Planning and costing agriculture's adaptation to climate change

Synthesis Report

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November, 2011

Funded by DFID

International Institute for Environment and Development

STOCKHOLM ENVIRONMENT INSTITUTE

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Citation:
Chambwera, M., Downing, T., Cabot Venton, C., Dyszynski, J., Crawford, V., Butterfield, R., Kaur, N., Birch, T. and Loga, D. 2011*. Planning and costing agriculture's adaptation to climate change: Synthesis Report.* International Institute for Environment and Development (IIED), London, UK.

This Synthesis Report was prepared by the project on Planning and Costing Agriculture's Adaptation to Climate Change, led by the International Institute for Environment and Development (www.iied.org). The Stockholm Environment Institute (www.sei-international.org/oxford) and the Global Climate Adaptation Partnership (www.ClimateAdaptation.cc) were core partners, along with teams in five developing countries. This report is based on a combination of literature reviews, country case studies, country stakeholder workshops and a global planning workshop and global synthesis workshop of all project partners from developed and developing countries. The five country study reports and a Policy Perspectives paper are available from www.iied.org. The project was funded by the UK's Department for International Development (DFID) under the Climate Change, Agriculture and Food Security Policy Research Programme.

Acknowledgements:

The authors would like to thank the following country case study teams for their contributions to the overall project on planning and costing agricultural adaptation to climate change, from which this Synthesis Report was derived: Malawi (George Matiya, Rodney Lunduka and Margaret Sikwese); Tanzania (Siza Tumbo, K. Mutabazi, A. Kimambo and F. Rwehumbiza); Nepal (Bikash Paudel, B.B. Tamang, Krishna Lamsal and Pratima Paudel); Rwanda (Jean Chrysostome Ngabitsinze, Adrie Mukashema, Mireille Ikirezi and Fidèle Niyitanga); and Bangladesh (Nazria Islam, Khandaker Mainuddin, Aminur Rahman and Saad Quasem). Sam Bickersteth, Simon Anderson and Dr Moinul Islam Sharif provided strategic guidance in the shaping of the whole project. We would also like to thank Kate Lee for providing the overall administrative support to the project, Chris Jack for generating downscaled climate envelopes for the country case studies, and Mel Kelly for editorial support.

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Acronyms and abbreviations

AEZs	Agro-ecological zones
AR4	IPCC *Fourth Assessment Report: Climate Change 2007*
ARD	Agriculture and rural development
ARDD	Agriculture and Rural Development Day
ASDP	Agricultural Sector Development Programme, Tanzania
AWG-LCA	Ad Hoc Working Group on Long Term Cooperative Action (UNFCCC)
BBS	Bangladesh Bureau of Statistics
CAADP	Comprehensive Africa Agricultural Development Programme
CBA	Cost-benefit analysis
CBS	Central Bureau of Statistics, Nepal
CC	Climate change
CCAFS	Climate Change, Agriculture and Food Security
CDM	Clean Development Mechanism
CGE	Computable Generalised Equilibrium
CGIAR	Consultative Group on International Agricultural Research
CIRAD	Agricultural Research for Development, France
CMIP3	Coupled Model Intercomparison Project
COP	Conference of the Parties (regularly scheduled meeting of the parties to the UNFCCC)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWSs	Coffee washing stations, Rwanda
DAES	Department of Agricultural Extension Services, Malawi
DFID	Department for International Development, UK
DRR	Disaster risk reduction
DSSAT	Decision Support System for Agrotechnology Transfer
EIARD	European Initiative on Agricultural Research for Development
FAO	Food and Agriculture Organization of the United Nations
GCAP	Global Climate Adaptation Partnership
GCF	Green Climate Fund
GCM	Global climate model
GDP	Gross domestic product
GDPRD	Global Donor Platform for Rural Development
GEF	Global Environment Facility
GHG	Greenhouse gas
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
ICHRP	International Council on Human Rights Policy
IFAD	International Fund for Agricultural Development

IFF	Investment and financial flows
IFPRI	International Food Policy Research Institute
IIED	International Institute for Environment and Development, UK
ILO	International Labour Organization
IPCC	Intergovernmental Panel on Climate Change
IRW	Internal renewable water
ISAR	Rwanda Agricultural Research Institute
KPAF	Kyoto Protocol Adaptation Fund
LAPAs	Local adaptation plans of action
LCD	Low Carbon Development
LDCF	Least Developed Countries Fund
LDCs	Least Developed Countries
MDGs	Millennium Development Goals
MOAC	Ministry of Agriculture and Cooperatives, Nepal
NAEB	National Agriculture and Export Board, Rwanda
NAMAs	Nationally Appropriate Mitigation Actions
NAPs	National adaptation plans
NAPAs	National adaptation programmes of action
NCAR	National Center for Atmospheric Research
NGO	Non-governmental organisation
NRC	National Research Council, USA
NWP	Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change (UNFCCC)
OCIR-Café	Rwanda Café Authority
ODA	Official development assistance
ODI	Overseas Development Institute, UK
OECD	Organisation for Economic Cooperation and Development
PRSPs	Poverty reduction strategy papers
REDD	Reducing emissions from deforestation and degradation
RH	Relative humidity
SBI	Subsidiary Body for Implementation (UNFCCC)
SBSTA	Subsidiary Body for Scientific and Technological Advice (UNFCCC)
SCCF	The Special Climate Change Fund
SEI	Stockholm Environment Institute
SWAPs	Sector-wide approaches
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
URT	United Republic of Tanzania

Executive summary

The agricultural sector has a crucial role to play in meeting development goals around the world. Not only is the sector responsible for meeting demand for food – expected to increase by 70 per cent by 2050 as income grows and the global population soars to over nine billion (OECD/FAO 2009) – it also has a major influence on essential ecosystem services, and provides a livelihood for 40 per cent of the global population and, directly or indirectly, for the 70 per cent of the poor in developing countries who live in rural areas (IAASTD 2009). Additionally, growth in the agriculture sector is vital in inducing wider economic development, with cross-country estimates showing that GDP growth originating in agriculture is at least twice as effective in reducing poverty as GDP growth originating outside agriculture (World Bank 2008). Unfortunately however, the sector has suffered from underinvestment over the past 20 years, with spending on agriculture by developing country governments either declining or remaining the same between 1980 and 2004 (Hoffmann 2011). It is only recently that national governments and international donors have begun to channel their efforts towards agriculture, with for example the World Bank choosing ‘Agriculture for Development’ as the focus of its 2008 *World Development Report*, and increasing its loans and investments for agriculture by 50 per cent to US$6bn in 2009. Agriculture is also the sector through which most developing countries will feel the earliest impacts of climate change, affecting their livelihoods and economies and restricting their ability to achieve their development goals.

The changing climate will have adverse effects on food production, food distribution, infrastructure, land availability for agriculture, and livelihood assets and opportunities in rural and urban areas. Adapting food systems to both enhance food security for the poor and to prevent the future negative impacts of climate change will require attention to more than just agricultural production. Food security can only be ensured and enhanced through a range of interventions across different agricultural systems and along the associated value chains, from production to distribution and allocation.

The current efforts to get agriculture into the global climate policy framework after the expiry of the Kyoto Protocol emphasises mitigation. Adaptation is an equally important objective in a world that cannot avoid climate change any more because of already accumulated greenhouse gases. In developing countries, adaptation is the primary concern due to their vulnerability to climate change and high dependence on weather-dependent agricultural systems. A complete response to climate change that integrates agriculture should therefore pursue both agricultural mitigation and adaptation. In order to plan for adaptation effectively, policymakers need reliable information from developing countries on the nature of adaptation, its costs, and how these are related to ongoing efforts to develop the agriculture sector and food systems of developing countries. Ignoring the linkages between adaptation and agricultural development could lead to duplication and inefficient use of scarce resources, or even to interventions in one area that conflict with the goals of the other. For example, a focus on maximising food production could promote mono-crops that foreclose the ability of farmers to diversify their food sources. Given that developing country agriculture is already being affected by climate variability and other development constraints, the greatest promise that a new global climate change policy framework offers is the potential to enable these countries to move from a focus on negotiations to one on action, through effective planning tools and resources for implementing their plans.

This study set out to inform climate policy development by analysing agricultural adaptation in developing countries using a combination of desk studies and country case studies in order to provide a framework, suggest areas to focus on when planning agricultural adaptation, and compute the likely costs. It comes against a background of increasing recognition by both the climate change and agricultural development communities that agriculture needs to be part of a new global climate change deal, and that the agricultural community needs to integrate climate change into its plans and programmes. 'No agriculture, no (climate change) deal' and related messages coming out of several stakeholders are clear signals that agriculture will be a key feature of climate change negotiations (see: http://www.fanrpan.org/documents/d00948/; http://ccafs.cgiar.org/blog/unless-we-address-agriculture-redd-will-not-be-successful-report-back-bonn).

Costing climate change adaptation has been a focus of several global economic studies that provide guidance to global decision makers, yet with little attention to the details on the ground. The range of previous estimates has been quite wide. Estimating a single global adaptation price tag for the present and the future covering all agricultural systems is not realistic, whether one is working from the top or from the bottom. Neither is there a single approach for planning adaptation that suits every community or country. As such, a universal costing and planning methodology does not exist. What is most feasible is a generalised framework that can be applied in different ways in different settings to meet clearly specified needs. Some instances may require planning and costing a single technology project, while others need planning and costing mainstreaming adaptation in national plans. This study followed key steps for bringing together global and local perspectives for the benefit of both global stakeholders and developing countries. These steps included:

1. A review of the literature on the impacts of climate change on agriculture and food security at the global level (with a specific focus on developing countries) and the resultant economic impacts of climate change through agriculture.
2. A review of the existing evidence and previous methods that have been used to estimate the costs of agricultural adaptation.
3. Development of a methodological framework for case study research for planning and costing developing country agricultural adaptation that reflects the diverse and heterogeneous nature of developing country agriculture and its multiple-objective orientation, including the livelihood and development pursuits of developing countries.
4. Case study research in five countries, each focusing on a different agricultural system that demonstrates the different ways in which adaptation could be implemented, and the likely costs.
5. Analysis of the current and emerging climate change and agricultural development policy frameworks that shape local-level responses to climate change and food needs, including the key players and processes underway.
6. Country feedback workshops that provided an opportunity for the project to learn from country stakeholders and experts, leading to the refinement of findings.
7. A synthesis workshop with country-level researchers to come up with key messages from country research as well as lessons learnt from using the analytical approach.

Linking climate change, agriculture and food security

On a global scale, climate change will negatively affect crop production in sub-Saharan Africa, Latin America, South Asia and Southeast Asia. While cereal production in Southeast Asia could increase, rainfed crop production will decline. In all these regions, the yields of the most important crops required for food security are depressed by climate change. In developing countries, agriculture is important for providing food as well as being a primary source of livelihoods. With the main elements of food security being food availability, accessibility, utilisation and food system stability, adaptation should also target production and non-production aspects of agriculture.

At the same time, agriculture also makes a significant (14 per cent) contribution to greenhouse gas emissions, with 74 per cent of these coming from developing countries (FAO 2009). On the one hand, meeting the increasing food needs of developing countries using the existing level of carbon intensity increases emissions in absolute terms, further exacerbating global warming and future climate change. On the other hand, reducing emissions without increasing food production and utilisation would increase the food insecurity that already exists in most developing countries. Agricultural mitigation, however, is not addressed in this study.

Existing cost estimates and methods

Adaptation costs have been estimated using different approaches, ranging from top-down approaches to bottom-up approaches, either covering all sectors or selected sectors. The most common approaches that have been employed so far include: integrated assessment models (IAMs), investment and financial flows (IFFs), Ricardian models, and Computable Generalised Equilibrium (CGE) models. These approaches have been criticised for not being able to reflect detailed realities at the local levels and for missing out the distributional effects of climate change and adaptation strategies. Other approaches, especially in the agriculture sector, have followed specific adaptation pathways such as: adaptation by changing cropping patterns, adaptation by developing new crop varieties, changing livestock patterns, adaptation using irrigation, or adaptation using research. These follow narrowly-construed adaptation pathways that assume agricultural systems that are dominated by these production approaches.

Developing country-based adaptation planning and cost estimation has mostly been achieved through national adaptation programmes of action (NAPAs). Local adaptation plans of action (LAPAs) are also emerging as ways of adaptation planning in developing countries. The details of these are context specific, with total NAPA costs around US$2 billion while LAPA costs are still evolving. The total cost of agricultural projects in NAPAs is US$118.4 million, ranging from US$16,700 to US$18.5 million.

The existing global estimates of adaptation costs are highly variable, ranging from US$4 billion to US$100 billion per year, depending on the study. The 2010 global cost for agriculture estimated by the World Bank (2010a) was about $7.6 billion per year, representing the cost of countering the effects of climate change on children's nutrition levels. Each estimate is a function of the model construction and the assumptions behind it. For instance, the 2010 World Bank study on the economics of adaptation to climate change (EACC) used agricultural research, irrigation efficiency, irrigation expansion and roads as the key cost variables. The outcome could change – for example if extension is included in the cost function. The same applies to many other methods. Instead of simply applying the same methods in different countries, this study started at the point of framing developing country agriculture and its adaptation as part of methodological development, and assumed that methodology is linked to purpose.

Planning and costing agricultural adaptation: factors to take into account

At the theoretical level, costing and planning adaptation is a simple exercise involving the identification of the likely impacts of climate change and their required responses, followed by constructing the budget required to undertake these responses and aggregating them across different scales – from local to country to global. There are, however, numerous complexities that need to be addressed ranging from the nature of developing country agriculture to the methodological difficulties of employing planning and costing techniques to an emerging and vaguely-defined field such as adaptation. These complexities include:

- Limited scientific information on the exact nature of future climatic trends in specific areas, given that trends and impacts are unevenly distributed even in the same country. In some cases attributing observed events such as floods or yield losses to climate change when siltation, diseases and soil degradation are existing problems is difficult.
- The diversity of agricultural systems in developing countries, rendering adaptation responses based on single crop models covering entire regions inappropriate. Different regions and even localities have different agricultural systems. In most developing countries, livestock, food and cash crops are often part of an integrated farming system.
- Short-term planning horizons that make it difficult to accurately estimate long-term adaptation actions and their costs.
- Separating responses to multiple stimuli: adapting to climate change, coping with existing climate variability, and addressing development deficits and agricultural inefficiencies.
- Multiple adaptation objectives – ranging from specific adaptation interventions such as irrigation and improved crop varieties, to approaches (such as building adaptive capacity) that target several variables that support livelihoods. There is a clear lack of boundaries on the variables that get into a costing function.
- Multiple actors at different levels have a role to play in agricultural adaptation including farming households, government, the private sector and others. Actions at one level or by an individual stakeholder in isolation are not sufficient, requiring investments at different levels to attain the same goal. Yet each actor has their perspective, motivations and different sets of factors influencing them.
- Integrating agricultural production and non-production functions of agriculture, to include entire value chains into costing functions.
- Limited data availability, especially in developing countries.

These complexities demonstrate why most adaptation economic studies have gaps and the cost estimates vary from study to study.

A new way of framing agricultural adaptation for costing and planning

This study proposes an alternative approach for framing and costing developing country agricultural adaptation that goes beyond just providing a global adaptation price tag, but one that could be used by decision makers as part of the process for planning, implementing and deploying adaptation funds. First, developing country agriculture is not homogenous, even within the same country, and has multiple goals such as food, informal employment, security, store of wealth etc. Thus adaptation needs to target specific agricultural systems that play specific roles for local communities and their countries. We distinguish cropping systems from livestock systems, subsistence from cash systems, and single crop systems from integrated cropping systems. Even this, as the study shows, is very coarse. The impacts of climate change on each of these systems, their development pathways, adaptation targets and players are different, and hence their costs are also different. Therefore basing impacts and adaptation measures solely on single enterprise models (such as crop yields) does not adequately inform specific planning at global and country levels.

Secondly, realising the close association between agricultural adaptation to climate change, coping with climate variability, and agricultural and rural development, the study frames adaptation as a pathway-dependent process that builds on existing coping strategies and development efforts to enable countries and communities to attain their goals and visions. Thus, adaptation is not treated as a specific state to be attained in isolation, but a learning process in which activities in one period build on activities and experiences from previous periods. Furthermore, there is uncertainty in the way climate is going to unveil (climate science is not precise, for example, on whether precipitation will increase or decrease in specific areas). Planning adaptation therefore takes into account existing country and global development plans and policies, especially in agriculture where there have been development efforts and funding over several decades by many players.

> Purposeful costing is part of the planning and implementation of adaptation, with or without external adaptation funds.

Finally, the study frames adaptation as a function of the inputs of actors at different levels in a country (national, district, local), with costs being incurred by various actors at each of these levels, thus suggesting the various levels of investing or deploying adaptation funds within a country. The specific relationships are, however, expected to differ by agricultural system and by country, thus the evidence can only provide signatures of such linkages rather than generally applicable prescriptions for all countries. Neither can signatures be aggregated to global levels without overly overstating or understating the costs of adaptation, a case that is clear in most adaptation costing studies. When these variables are defined at the different levels in a country, then costs can be assigned from sources such as surveys, focus group discussions, and budget analyses that we employed in different countries.

Table 1: Characteristics of the agricultural systems used in the case studies' research.

Country	System description	Primary goal	Defining feature	Associated functions and enterprises
Tanzania	Pastoral livestock systems	Store of wealth	Extensive livestock management based on mobility and minimum external input use	Maize, *lablab* (type of bean), cowpeas, sorghum, millet
Nepal	Integrated maize-based farming systems in the mid-hills	Food sufficiency	Integrated farming with mixed cropping	Maize, rice, wheat, legumes, millet, livestock, vegetables, fruit trees
Malawi	Subsistence rainfed food production	Food security	Smallholder maize production	Tobacco (for cash), cassava, sweet potato, beans and some livestock
Rwanda	Smallholder cash-cropping	Cash	Perennial crops dominated by coffee	Banana, Irish potato, maize, beans, livestock/cattle
Bangladesh	Deltaic, flood-prone cropping systems	Food and livelihood security	Saline-prone rice production in lowland areas at small and medium scales	Fisheries and aquaculture, livestock, vegetables, pulses, potatoes, maize, wheat

Main case study findings

Key adaptation actions and costs

The adaptation responses in the case studies are not single actions, but packages of coordinated responses by actors at local level (farmers), district level and national level, referred to as 'signatures' in this study because they depict a possible or representative way in which adaptation could be planned and delivered in a specific area. This could change in a different agricultural system in the same country, or in the same agricultural system in another location.

The adaptation signatures developed by country case studies grouped adaptation actions into three levels, without implying these need to be implemented separately, but to reflect the different levels of decision making by different actors. A signature would typically consist of coping strategies, survival options and improvements in agricultural efficiency in one group of actions; another group consists of coping with climate variability, while the third group of actions deals with the impacts of climate change. National-level actions include research, institutional and policy development for climate change, early warning systems, coordination of actors, and training of experts. District-level actions, undertaken mostly by local authorities, government line ministries based at district levels and NGOs, include extension services, local capacity building, land-use planning, and provision of infrastructure. Local-level actions include the actions of households and businesses to implement specific actions with the support of district actors and NGOs, and on their own. These include crop and animal husbandry, livelihood diversification, and migrating to other areas (temporarily or permanently).

Table 2: The total cost of each signature, integrating relevant actions at different levels.

Country	Level	Annual cost now (million US$)	Annual cost to 2020 (million US$)	Assumptions /scale
Tanzania	Local	93.5	877.3	Entire country for the livestock sector
	District	169.2	1,600	Entire country for the livestock sector
	National	20.6	208	Entire country for the livestock sector
Nepal	Local	0.04	0.016	Two villages with a total of 600 households
	District	0.46	0.031	Coordination across 40 villages
	National	0.183	0.41	Coordination and facilitation (excluding major institutional adjustment, capacity building, national extension services)
Malawi	Local	16.05		Five-year budget rather than annual costs
	District	37.7		
	National	11.3		
Rwanda	National agriculture	14.2	130	Costs of national coordination of specific agronomic, institutional change and marketing activities
	Coffee	2.4	12.5	Turn-around programme for coffee sector, farm to national, including marketing
Bangladesh	Local	0.827	2.5	Assumes all activities at national and local levels are coordinated by designated government departments
	District	0.819	7.3	
	National	10.3	32.4	

When assigned to the different actors implementing the adaptation interventions, the signatures form the basis for national planners, donors and others to integrate them into their development and sectoral plans, as well as implementing institutional changes reflecting actions and players at different levels. For example, in most case study countries, awareness budgets are best allocated to government departments and NGOs with presence at the local and district levels, instead of creating new structures in players who are only based at the national level. The global policy environment should then derive its policy options from these realities.

In-country implementation and institutional coordination

Policy and institutional analyses in case study countries show that there is a current separation between the lead climate change institutions and the sectoral institutions that would ultimately be responsible for implementing specific adaptations. Ministries of agriculture, in particular, are not directly involved in climate change policy processes, and are at times indirectly involved in agricultural adaptation projects. This is inconsistent with the local presence of different institutions in farming areas. Agricultural institutions have the structures for delivering the adaptation actions at all levels, while the lead climate change institutions have limited presence.

While it may seem preferable to get agricultural ministries as lead agencies for agricultural adaptation, experiences with agriculture sector-wide approaches (SWAPs) suggest that caution needs to be taken to avoid the tendency by agricultural ministries to focus on interventionist approaches that solely prioritise public expenditure and public service delivery, neglecting the role of other approaches and players (such as promoting the private sector and market approaches). The findings from this study, based on its approach, show that adaptation is a function of the actions of different players operating at different levels, although government has an important role to play.

The lessons from agriculture SWAPs also warn against the focus on donors at the expense of local delivery. This is critical for climate change adaptation that depends heavily on external resources, where external requirements override or overburden delivery in vulnerable communities.

Lessons from national adaptation programmes of action (NAPAs) and local adaptation plans of action (LAPAs) show that planning adaptation from local levels provides a broader base for action, and identifies the most specific actions required at the local level, which could form a good basis for deploying adaptation finance. The approach used in this study boded very well for the future, and was able to benefit from the Nepalese LAPA process (LAPAs assemble more comprehensive information at the local level than do NAPAs).

The global policy perspective

The global policy environment gives countries the capacity and appropriate signals to implement their adaptation and development actions on their own, as global actors have limited experience and capacity on the ground. While agriculture is not yet formally integrated into the negotiations, the proposals, submissions and the stakeholder processes running alongside the negotiations demonstrate that agriculture is a key part of the climate change solution from both mitigation and adaptation angles. The agricultural dimension of the negotiations – and the resultant global policy – need to draw on the strengths and experiences of existing agricultural development processes, as well as those of the private sector. Harmonisation is also important to make the most of the limited adaptation and agricultural development resources that are currently available. At the moment, there is a mismatch between global policies and national-level institutional and planning frameworks with regards to agricultural adaptation, as climate change is still very much viewed as the responsibility of environmental departments.

The role of the private sector and markets

The global private sector has started to make significant investments in addressing climate-related agricultural stresses facing developing countries, mostly in the areas of seed production and research. It could also be a significant player in technology development and deployment. This huge potential needs to be coordinated in the policy, together with science to address some of the concerns being raised on environmental grounds to ensure developing country welfare and to avoid maladaptation. At the country level, the role of the private sector and market channels is most clear in cash cropping systems, which are mostly linked to global markets. Initiatives (such as Fairtrade) that reward farmers for engaging in sustainable production processes have the potential to be extended to adaptation. Similarly, adaptation along cash-cropping value chains, as in the coffee sector, would involve the private businesses in the value chain adapting their operations to climate change. In non-cash-based agricultural systems, the role of the private sector in adaptation (valued at US$30 million in the Malawi case study) involves market linkages and credit facilities.

There is, however, a general lack of private sector and market-based perspectives in most developing country policy and planning processes, as most planning and funding is based on external, donor funding. This needs strengthening. The involvement of the private sector, however, requires appropriate business models that distribute benefits equitably across a wide spectrum of players.

Key messages and implications for planning and future costing studies

Climate change policy needs to integrate both agricultural mitigation and adaptation, and tap into the potential co-benefits that exist between the two (these were not investigated in detail under this project). In as far as adaptation is concerned, its scope needs to be widened beyond just the production aspects, as a narrow focus on productivity limits the ability to meet food security, especially of the most vulnerable who face production, access and utilisation constraints. These ideals could be supported by global and national policy frameworks that build upon existing agricultural development activities, and also provide for the involvement of the private sector. Their implementation is context-specific, involving highly complex combinations of planned and autonomous responses by actors at different levels who are pursuing different objectives. The associated institutional arrangements and implementation costs are highly variable, depending on context and the focus of the actions, whether local or national. After a detailed analysis of the literature and undertaking specific case study research in five countries, the key messages for global and national policymakers focus on:

- Adaptation decision making: how can we choose effective adaptation pathways across levels and actors?
- Agricultural adaptation: what do adaptation pathways for the agriculture sector look like?
- Costing findings: how much is agriculture's adaptation going to cost?
- Institutional coordination: how can institutional coordination be enhanced to support this process?

A. **Adaptation decision making**

- There are an infinite number of possible adaptation futures and pathways. A 'signatures approach' reduces this to a more manageable but still very large subset of possible actions and plans that can be pursued by countries.
- At least in the short term, countries are capable of developing adaptation plans with limited access to complex (and mostly unavailable) scientific climate change projections. At a community level, sophisticated climate change information becomes less relevant for decision making, as adaptation is very much based on existing conditions, especially where climate variability is already a factor. However, climate change information specific to each country and its local regions needs to be developed beyond what is currently available, and used to inform forward planning and to avoid maladaptation.
- National-level institutions may have very different perceptions as to the nature of the climate change problem and the best forms of adaptation. These need to be harmonised.

B. **Agricultural adaptation**

- Research, capacity building and extension are the common pillars for effective adaptation across all agricultural systems. With current information on climate change, these are the most effective and least risky areas for investing in building adaptive capacity in addition to variable, locally-specific actions. Most local, district and national stakeholders use local climate perspectives for planning adaptation, with insignificant use of formal climate science models, and their view on adaptation is the scaling-up of existing methods for coping with climate variability.
- The adaptation actions prioritised by both institutions and farmers tend to be extension (and awareness), scaling-up of existing methods for coping with climate variability, and research and institutional capacity building. The specific detailed actions are limited by all stakeholders' limited knowledge of future climatic trends and development scenarios.
- The scope of agricultural adaptation: production and non-production aspects need to be adapted to climate change and used as adaptation approaches, including value chain adaptation.

C. **Costing findings**

- The immediate costs of adapting different agricultural system signatures from local to national level is highly variable, ranging from US$0.3 million per year to US$283.3 million per year. These are context-specific and depend a lot on the variables used in the estimations and the areas of focus prioritised by local stakeholders. There is no uniform distribution of costs by level, meaning the allocation of funds to each of these levels also has to be context-specific. The costs will increase over time across all agricultural systems.
- Top-down adaptation costing approaches do not accurately reflect (and often underestimate) the cost of adaptation, but bottom-up approaches are highly sensitive to level of detail and development variables and thus cannot be aggregated to arrive at realistic global estimates. Any bottom-up cost estimate should be done to fit its specific purpose, and not all purposes generally.

- Isolating and precisely estimating the 'costs of adaptation' within planning is not possible as most climate change impacts are interwoven with development, social and environmental problems such as poverty, deforestation, siltation, and energy access. The required adaptation actions also tend to partly address these problems.
- A key economic consideration for agricultural adaptation is where to invest the limited adaptation funds. Adaptation funding must be invested at national, district and local levels to achieve the best impact in the short and long term, and be targeted at various actors who play several roles that enhance overall effectiveness.

D. **Institutional coordination**

- Clear assignment of institutional responsibility for coordinating climate change adaptation in a country will enhance effective action at all scales in developing countries. This should not be solely focused on adaptation with the aid of external resources, but adaptation based on countries' need to avoid future consequences of climate change.
- Adaptation should be mainstreamed into existing institutions, planning processes and programmes at both national and local levels, because creating new institutions adds complexity and duplication.
- The opportunities for private sector involvement in adaptation could be significant, and private sector involvement is already evident at the global level. But private sector opportunities at the country level need to be evaluated and quantified – including insurance, fair trade, etc. Cash crop enterprises provide the best opportunities for private sector and market-driven adaptation approaches. Adaptation policies should harness private sector and market-based opportunities to promote adaptation, thereby reducing public demand for adaptation funds.
- Implementation of agricultural development and adaptation activities at the country and local levels need not be separated, while institutional coordination at national level is required to ensure that climate change is integrated in all agricultural development activities, policies and development plans.
- Global coordination and harmonisation across climate change policy processes, agricultural development and the private sector will deliver appropriate signals and resources that are required at country levels, including traditional and new development partners such as China and Brazil, who have an increasing role and influence in the development patterns of developing countries.

The study concludes that planning agricultural adaptation should be done at country level, and any economic studies should be tailor-made to meet the planning and implementation needs of individual countries rather than those of donors. Capacity development at country level should be focused on aligning agricultural adaptation with existing agricultural development and wider country frameworks, and economic assessments need to focus on how to make this cost-effective by investing at relevant levels and involving a wider range of stakeholders, including the private sector.

1. Introduction

1.1 Agriculture, development and climate change

Climate policy has related to agricultural development through several concerns. Foremost is the global policy to avoid dangerous climate change. And mitigation inherently involves agriculture, whether through direct emissions or the consequences of global mitigation actions. The development agenda is increasingly taking on climate change, as seen in prospects for achieving development goals and promoting food security for all, and the efforts of the Global Donor Platform for Rural Development (GDPRD 2009).

Avoiding dangerous and costly climate change requires an ambitious global policy that translates into action at all levels of society and in all sectors. Failure to act now will cost the global economy 5 - 20 per cent of purchasing power (Stern 2006). A new global climate deal that replaces the Kyoto Protocol could be in one of the three scenarios reflecting the level of action and commitment made at the global level (Ott 2007). On the one hand, a business-as-usual scenario characterising failure by post-2012 negotiations to yield significant emission reductions, locking the world onto a fossil fuel path. On the other hand, an ambitious and effective post-2012 scenario could agree deep cuts in emissions, with adequate financial means made available to least developed countries to adapt to the climate change that will result from greenhouse gases already accumulated in the atmosphere.

The greenhouse gases (GHGs) leading to climate change are largely emitted by a variety of human activities, ranging from heavy industrial and domestic use of fossil fuels in developed countries to agricultural activities and cutting of trees in developing countries. With due consideration made for the principle of common but differentiated responsibilities and capabilities to address climate change, a viable solution will involve addressing both the causes and impacts of climate change. The IPCC *Fourth Assessment* recognized the different sectors contributing to climate change and those that are heavily affected. Agriculture is one sector making a significant contribution to GHG emissions and it is at the same time affected by climate change, particularly in developing countries.

A recognition of the potential role of agriculture in mitigation, and the need to adapt it to climate change, has led to growing calls for it to be part of the global climate change policy process, which builds up towards a new agreement after the expiry of the Kyoto Protocol in 2012.

Both mitigation *and* adaptation will be important components of a post-2012 climate change deal. Informing the policy debates and plans for agricultural adaptation requires a clear understanding of the value of agriculture, the nature of its adaptation, and the cost of doing so. Adaptation is a long-term process, involving both a transitional phase and an equilibrium phase (Tol *et al.* 1998). Furthermore, agricultural adaptation is closely linked with agricultural development, food security and poverty reduction.

The agricultural sector has a crucial role to play in meeting development goals around the world. Not only is the sector responsible for meeting demand for food – expected to increase by 70 per cent by 2050 as income grows and the global population soars to over 9 billion (OECD/FAO 2009) – but it also has a major influence on essential ecosystem services, and provides a livelihood for 40 per cent of the global population and, directly or indirectly, for the 70 per cent of the poor in developing countries who live in rural areas (IAASTD 2009). Additionally, growth in the agriculture sector is vital in inducing wider economic development, with cross-country estimates showing that GDP growth originating in agriculture is at least twice as effective in reducing poverty as GDP growth originating outside agriculture (World Bank 2008). Unfortunately, however, the sector has suffered from underinvestment over the past 20 years, with spending on agriculture by developing country governments either declining or remaining the same between 1980 and 2004 (Hoffmann 2011). It is only recently that national governments and international donors have begun to channel their efforts towards agriculture with, for example, the World Bank choosing 'Agriculture for Development' as the focus of its 2008 *World Development Report*, and increasing its loans and investments for agriculture by 50 per cent to US$6bn in 2009.

Climate change adds a new dimension to discussions about agricultural development. On the one hand climate change will impact directly on agricultural productivity: despite expected productivity increases in certain temperate areas, overall it is expected to cause considerable yield declines (IPCC 2007). A recent study by the International Food Policy Research Institute (IFPRI) estimates that climate change could reduce yields of irrigated wheat and rice by 30 per cent and 15 per cent respectively, with important consequences for food security and malnutrition (Nelson *et al.* 2009). On the other hand, agriculture is responsible for 13.1 per cent of global GHG emissions (IPCC 2007) and must play an important part in mitigation efforts. This complex relationship has encouraged the thinking about agriculture and food security to move away from the use of fossil fuel-intensive farming techniques towards a more holistic approach emphasising the multi-functionality of agriculture and offering a wide range of place-specific options that improve food security, increase adaptive capacity, and contribute to mitigation – in what Anderson *et al.* (2010) describe as a 'diametrical paradigm shift'.

With agriculture climbing the development agenda and its relationship with climate change becoming clearer, a new international focus on agriculture *and* climate change is emerging, evident in both agriculture and climate change spheres. From a climate change perspective, the World Bank, together with a group of world leaders and policymakers, announced the *Roadmap for Action: Agriculture, Food Security and Climate Change* at COP16 in Cancun, calling for a more central role for agriculture in addressing climate change and presenting agriculture as a solution to climate change (World Bank 2010b). The second UNFCCC 'Agriculture and Rural Development Day', held in parallel to the climate talks at COP16 in Cancun, built on the success of the first in Copenhagen in bringing attention to the links between agriculture, climate change and food security in international climate negotiations. Although the hoped-for COP decision on the establishment of a 'work program for agriculture' failed to materialise, the outlook for a decision at COP17 in Durban looks more promising.

With these perspectives, this study focuses on: building a knowledge base on how adaptation in agriculture could be planned; what constitutes the cost of adaptation; and how adaptation actions could be harmonised with existing efforts to develop this sector in developing countries. These are critical elements of policy at the international level and in developing countries. In doing this, we draw on the perspectives of both the global climate change and the agricultural development processes, backed by developing country evidence. This is crucial to fill the existing gap in evidence from developing countries that is required to inform climate change policy.

1.2 Demand for an informed response

Hoffmann (2011) recognises that bold visionary measures at the national and international level are required to transform agriculture in a way that enables it to meet the challenges of climate change and food security. Global policies provide the frameworks that enable local action in places where adaptation is required, as well as the generation and appropriate deployment of adaptation funds. The Global Donor Platform for Rural Development (GDPRD 2009) has specifically called for agriculture to be made part of post-2012 climate policy agreements. With international processes slow, developing countries can still move ahead with their actions. Addressing climate change action and policy requires players at all levels to be involved, rather than relying solely on global policy processes, and is consistent with Ostrom's polycentric approach towards addressing climate change (Ostrom 2010), in which effective climate change action will require the involvement of players at all levels, local to global. The climate change regime requires good understanding of the way in which agriculture, especially in developing countries, works – from the adaptation responses to the policy and institutional frameworks in which agricultural adaptation is being addressed. Global policies that work are informed by realistic expectations of what works on the ground.

A global adaptation response policy is only effective with adequate financial resources to deploy in vulnerable places. Thus data on actual costs of adaptation are crucial to guide global fundraising and planning. Previous attempts to put a price tag on adaptation have yielded the ranges of the amount of funding that needs to be raised. They do not, however, go into the details of how and where these resources need to be deployed, and what kinds of activities will be undertaken at different levels as part of adaptation. The relationship between these adaptation actions with respect to existing work in specific sectors has also not been clearly spelt out to provide value addition and avoid duplication or maladaptation. Similarly, the linkages between global frameworks addressing climate change adaptation and agricultural development, including funding, need to be explored.

Any linkages at the global level need to reflect the realities at the country level, which also mirrors the local level. The role of the private sector in funding adaptation is also not clearly established. Thus if agriculture is to be a feature of post-2012 climate change agreements, a detailed understanding of the required adaptation actions, timeframes, players involved, and key cost areas (among others) is required. This knowledge should inform action at all levels, from the local level through national to the global levels.

1.3 Contribution of this study and its approach

Adaptation, mitigation and food security are all issues that agriculture needs to deal with in the face of climate change. This study focuses on the planning and costing of agricultural adaptation in developing countries. In order to inform the ongoing policy processes as well as actions in developing countries, this study provides an evidence-based analysis of agricultural adaptation in developing countries that generates key messages about both the nature of developing country agriculture as well as the key elements of adaptation that constitute the costs of agricultural adaptation.

The point of departure is that agriculture is highly heterogeneous and therefore will differ from one form of agriculture to another and from one region to another, for example cropping systems of Asia or pastoral livestock systems of Africa. Recognizing the close relationships between adaptation and agricultural development, the study addresses the policy issues that drive the agriculture of developing countries (from both development and climate change angles), as well as some of the ongoing and emerging global policy processes within and outside the climate change regime. Also, recognising the various economic studies on the costs of climate change adaptation that have been undertaken recently to inform global policies, the study uses a bottom-up approach that demands first of all a clear conceptualisation of the adaptation processes and pathways in developing countries as the basis for costing adaptation. This is intended to provide a stronger basis for long-term adaptation planning given that climate change information is limited and that adaptation is likely to be a stepwise process rather than a one-off event.

The conceptualisation of adaptation as a process that responds to changing and uncertain climatic stresses and shocks suggested the need to map actions in space, over time, and in view of ongoing and planned agricultural development processes that are required even in the absence of climate change. Thus adaptation that follows non-linear development pathways – while intersecting local livelihoods and district and national plans constructed for different agricultural systems – formed the basis of analysing planning and costing agricultural adaptation. This provided insights into the level of complexity and detail that requires attention in the process of adaptation planning, and the issues that global policymaking needs to take into account. The bottom-up approach also enabled the study process to interact with players at all levels of planning and action, thereby ground-truthing findings in the process. Thus the perspectives of local community farmers, district planners and community-based organisations, as well as national-level experts and policymakers, significantly shape the content of the study. They provide the difference between top-down planning processes and local-level realities of addressing climate change impacts in agriculture.

Agricultural adaptation is required and could have a considerable cost given the diversity of agricultural systems and the scale of effort required.

The specific contribution of this study to an informed climate change policy regime that takes agriculture into account stems from the following considerations that shape the approach that it has taken.

1.3.1 Adaptation as a priority for finance

This study has a specific focus on adaptation while recognizing the need for both adaptation *and* mitigation in the agriculture sector. Although debates about climate change have, until recently, focused largely on mitigation, the key role that adaptation has to play is becoming increasingly clear across a range of sectors, not least agriculture. Essentially, momentum within the climate system means that even if we stabilise our GHG emissions at current levels there is a 75 per cent chance that temperatures will rise 2°C above present-day levels, and a 20 per cent chance they will rise by 3°C (Met Office website, accessed 01.09.10). Climatic changes of this order of magnitude would impact considerably on society and have the potential to slow or even reverse development; adaptation is vital to reduce these adverse effects.

The IPCC AR4 (*Fourth Assessment Report: Climate Change 2007*) concluded that adaptation and mitigation are policy complements and not substitutes. Planning agricultural development increasingly evaluates both adaptation and mitigation, although rarely as trade-offs. Climate change negotiations and programmatic planning remain largely divided, with mitigation and adaptation considered as separate concerns. This has historic roots in the negotiations of international finance and distribution between developing countries. Nevertheless, recent proposals for a UNFCCC work programme on agriculture (e.g., the FAO submission and the 'Agriculture and Rural Development Day' at COP15 in Copenhagen) remain skewed towards mitigation – with adaptation mostly treated as a co-benefit of mitigation. Addressing mitigation and adaptation as complements gives both equal weight while enabling actors at local levels to use different entry points that are relevant to address their needs (adaptation or mitigation). For most developing countries, where livelihoods and economies are at stake as a result of the impacts of climate change on agriculture, financing adaptation is a priority but policies should provide them with options and incentives to generate mitigation co-benefits. This is a key knowledge area that this study has not pursued due to time limits.

This need for adaptation is increasingly recognised in the international policy arena, with a new Climate Adaptation Framework and Adaptation Committee established under the Cancun Agreements. This complements the existing Nairobi Work Programme, which focuses on improving understanding of impacts, vulnerabilities and adaptations to allow more informed decision making on adaptation, and the Least Developed Countries (LDC) Work Programme, which includes national adaptation programmes of action (NAPAs), providing LDCs with a process to identify priority actions in adapting to climate change. Existing global funds providing support for adaptation include the Kyoto Protocol Adaptation Fund, the World Bank Pilot Program for Climate Resilience, and the Global Environment Facility. Crucially, one of the issues not resolved at Cancun was the allocation funding under the Climate Adaptation Framework, in part due to the lack of detailed information on specific adaptation needs. The adaptation focus of this study partly addresses this gap, providing the practical dimensions that need to be dealt with when considering agriculture as part of a global climate change agreement.

Agricultural adaptation is required and could have a considerable cost given the diversity of agricultural systems and the scale of effort required.

1.3.2 Bottom-up costing and planning

While political momentum surrounding the need for agriculture to adapt to climate change, and the need for international cooperation to support this, has built up in both agriculture and climate change circles, policymakers have begun to consider what this might mean in practice. Without a solid understanding of how agricultural adaptation happens on the ground there are few ways to verify global estimates of adaptation costs, and there is little guarantee that policies and programmes aimed at supporting agricultural adaptation will be well targeted and effective. Bottom-up views of agricultural adaptation play a crucial role in providing this perspective, supporting both national and international efforts towards agriculture's adaptation to climate change.

International and national policies must be developed on the basis of reliable information about both the processes *and* the costs of agriculture's adaptation on the ground: *where and when* to invest in agricultural adaptation, as well as *how much*. While it may be possible to roughly plan and cost adaptation separately at the global level using top-down approaches, planning and costing are fundamentally integrated processes that cannot be carried out effectively in isolation from a bottom-up perspective. Essentially, costing must be based on an understanding of *who will do what*, and planning must be based on an understanding of which combinations of adaptation options can be carried out with the limited resources available. Few studies have attempted to address the two together.

1.3.3 Pathways of adaptation across scales

Adaptation pathways are a series of decision nodes – actors making decisions about resources now and in a series of steps in the future. This is a fundamental departure from depicting climate change adaptation as a linear reaction to some prospective scenario of future climate impacts, say for the 2050s. It is firmly rooted in actual decision framings by real actors facing urgent issues. The project developed several such pathways in the case studies, depicting a range of adaptation strategies and actions for different agricultural systems. This approach to 'adapting well' is a further development of the concept of adaptation signatures developed by the Global Adaptation Partnership (see an initial application in the economics of adaptation in Tanzania, Watkiss *et al.* 2010; Downing 2011 has some further elaboration of the concept).

Pathways of agricultural adaptation span scales: the roles of, and relationships between, different actors are not fixed as 'local' or 'national'. For instance, an adaptation signature based on the use of seasonal climate forecasts to adjust seasonal practices involves farmers making decisions for each field linked to global weather centres that issue seasonal outlooks, and intermediaries at the national and community level. Costing an agricultural signature requires understanding the relative efforts at different levels and their inputs into the adaptation process.

This pathway approach provides decision makers at various levels with information as to the costs of adaptation measures, who will bear the costs and benefits, and how such local costs scale up to plan adaptation finance at the national and international levels. While examples of both local-level and national-level adaptation are relatively well documented, particularly in the community-based adaptation literature and in government documents such as national adaptation plans of action, there is a dearth of studies linking adaptation actions across different levels and over time. The 5th International Conference on Community-Based Adaptation to Climate Change, held in Dhaka in March 2011, recognised this by its focus on 'Scaling Up: Beyond Pilots', however there remains a strong need for information on how stakeholders at different levels can work together on climate change adaptation.

Planning effective adaptation must be based on robust information at the local scale, taking account of realistic estimates of actual costs.

Identifying the level at which costs of key actions are borne, and the stakeholders responsible for those actions, is key for the planning and deployment of adaptation funds, and provides a material relationship between planned and autonomous adaptation. Similarly, the temporal dimension of adaptation is built into the study to take into account learning as well as the building of capacity to deal with uncertain and unknown future climatic patterns, and building on existing efforts to address climate variability and agricultural development needs. Indeed, there are several areas of agricultural improvements on which adaptation builds. In other words, by taking on scales and temporal dimensions of adaptation, issues of complexity in agricultural adaptation that planners as global and country levels need to take into account are addressed. The eventual pathway subsequently depends on the effectiveness of any given mitigation policy's ability to limit global warming.

1.3.4 Agricultural systems and adaptation signatures

In order to understand the complex processes of adaptation, the project undertook five in-depth case studies of adaptation of farming systems in different countries. This bottom-up approach recognises that agriculture is both multifunctional and heterogeneous: global results can only be based on a synthesis of local cases. Each agricultural system is affected by climate change in different ways and requires a different approach to adaptation.

The case studies were chosen to reflect a diversity of adaptation pathways:

- **Tanzania**: pastoralism and livestock systems adapting through mobility and natural resource management.
- **Nepal**: integrated maize-based farming in the mid-hills adapting to achieve food self-sufficiency on-farm.
- **Malawi**: subsistence rainfed food production to achieve on-farm food security.
- **Rwanda**: smallholder cash cropping adapting through integration into export markets.
- **Bangladesh**: coastal rice production adapting through livelihood security.

The use of agricultural systems to understand adaptation is also based on an understanding that agricultural players adapt to climate change in ways that enable them to meet wide-ranging needs, some of which are not a direct consequence of climate change.

> The diversity and scale of agricultural systems requires a robust knowledge base of effective adaptation strategies and actions in order to plan viable development pathways.

The system chosen for each country does not necessarily address the most dominant or most important system for that country. A system for each country was rather chosen to provide a demonstration of how the adaptation of similar systems in other countries could be approached. Other practical considerations were also taken into account in the choice of systems for each country. The same applies to the choice of local case study sites in each country. The findings from each of the case studies were then synthesised to provide global policy prescriptions, based on a detailed understanding of what agricultural adaptation means on the ground, what roles different actors play, and what costs are borne by these different actors.

1.3.5 Policy engagement

The study placed a high value on its engagement with policymakers, aiming to provide relevant information that will support their decision making. As well as being consulted during the research process, relevant stakeholders were been invited to a country-level stakeholder workshop held in each of the five case study countries to discuss the findings. It was hoped that this would increase interest amongst stakeholders in agricultural adaptation in general, and in the specific adaptation options suggested, allowing them to feed back into the country studies before the reports were finalised, and would provide a forum for the different stakeholders from both agricultural and climate change communities to come together to discuss agricultural adaptation.

> Adaptation pathways depict the progression from current agricultural systems as they develop capacity to adapt to additional climate change impacts over time and across scales.

1.4 Organisation of this Synthesis Report

This study informs decision makers by providing key messages from analyses carried out at three levels. At the conceptual level, the study develops an approach for planning and costing agricultural adaptation, which can be used by decision makers at global and country levels. At the country and local levels, the study provides five case studies that present local evidence that helps shape national adaptation planning, with indicative costs for the key adaptation functions and actions identified in the short and long terms. At these two levels, the study employs the conceptual approach developed earlier, and informs country level decision makers and the global community.

At the global level, the study provides a map of the global policy processes in the climate change arena and those in the agricultural development arena and analyses the emerging issues from both sides that should be considered when developing a new climate change agreement that takes agriculture into account. The flow of the sections is as follows:

Section 2 provides a review of climate change, agriculture and food security thereby putting the whole study into the general context of the issues around climate change and agriculture.

Section 3 presents a review of previous work on costing climate change adaptation, providing a background and reference for discussing the approach used in this study in order to address the gaps and weaknesses in preceding studies.

Section 4 develops a framework for planning and costing adaptation in agriculture that takes into account different agricultural systems, levels and timescales of adaptation, and local climate change information. This section also presents the procedures or steps used in undertaking country-level research, including policy analyses, downscaling of climate models, and local surveys.

Section 5 presents summaries of the case studies carried out in five countries.

Section 6 presents the global policy framework that is likely to shape a new climate change regime, and the extent to which agriculture is currently integrated. It also includes an overview of the key processes and players, bringing together agriculture and climate change from their respective angles.

Section 7 summarises the key messages from the entire study and their implications for policymakers. Detailed country studies are presented as separate standalone reports.

2. Climate change, agriculture and food security

This section emphasises the importance of incorporating agriculture and food security issues into climate change debates, both at a global level and in Africa and Asia specifically.

Rapidly increasing populations, technological change, public policies, economic growth and the closing margins of cost of production to price have been the main drivers of change in the agricultural sector during the last four decades. Production of food and fibre has more than kept pace with the sharp increase in demand in a more populated world. The global average daily availability of calories per capita has increased (with some notable regional exceptions). This growth, however, has been at the expense of increased pressure on the environment, and depletion of natural resources (Tilman *et al.* 2001; Rees 2003), while it has not resolved the problems of food security and child malnutrition suffered in poor countries (IPCC 2007).

Climate change is likely to impact on livelihoods and food security through more frequent and more intense extreme weather events, which will have adverse immediate impacts on food production, food distribution infrastructure, land availability for agriculture, and livelihood assets and opportunities in both rural and urban areas. Changes in mean temperatures and rainfall, increasing weather variability, and rising sea levels will all affect the suitability of land for different types of crops and pasture, the health and productivity of forests, the incidence of pests and diseases, and biodiversity and ecosystems. Loss of arable land is likely due to increased aridity, groundwater depletion and the rise in sea level.

The International Symposium on Climate and Food Security recognized three critical world problems, also mentioned by the IPCC AR4: that several billion people often lack the most basic human need – food security; that population growth and the need to improve living standards are putting severe pressure on the soil and water resources that sustain all food production; and that unfavourable weather and climate remain the most frequent causes of crop failure – sometimes leading to widespread hunger and even famine.

It also recognized a new factor: the growing scientific consensus that the buildup of greenhouse gases in the atmosphere is likely to cause a global climate change – an environmental change on a scale unprecedented in human history – with the potential for great impacts, both beneficial and harmful, on food security.

Although our understanding and certainty about climate changes and their possible impacts on agriculture has grown over recent few years, the overriding concern is how researchers and institutions can help farmers and communities exploit favourable agro-climate patterns and adapt to – or protect against – unfavourable climatic trends.

2.1 Global impact on agricultural crops

Most agricultural producers located in low income and less developed countries are typically operating well below their potential productive capacity. As noted by the FAO (2007) the developing world already contends with chronic food problems. Estimates suggest that this situation could worsen: around 11 per cent of arable land in developing countries could be affected by climate change, including a reduction of cereal production in up to 65 countries, and losses of up to 16 per cent of GDP in some cases. Table 3 summarises some of the impacts of a range of climate change scenarios (and models) on agricultural production across southern hemisphere regions.

Table 3: Estimated impact of climate change on agricultural production across southern regions (Source: Keane *et al.* 2009).

	Sub-Saharan Africa	Latin America	South Asia	South-East Asia
Temperature	Temperatures to increase by 3–7° C by 2080–2099.	Temperatures to increase by 1–7.5° C by 2070–2099.	Temperatures to increase by 2.3–4.5° C by 2070–2099.	Temperatures to increase by 2–3.8° C by 2070–2099.
Precipitation	Precipitation to decrease by up to 30–40% in most parts of southern Africa, but to increase by 7% in tropical and eastern regions by 2080–2099.	Precipitation to change by up to -40% to +12% by 2080.	Precipitation to increase by 10–17% by 2070–2099.	Precipitation to increase by 3–8% by 2070–2099.
Agriculture	Rain-fed cereal (wheat, maize, rice) production to decrease by 12% (net loss) by 2080, with great regional variations.	Overall grain yields to change by between -30% to +5% by 2080. For example, rain-fed wheat production is to decrease by 12–27% by 2080.	Net cereal production to decrease by at least 4–10%. For example, rain-fed wheat production is to decrease by 20–75% by 2080.	Overall cereal production to increase by up to 30%, but rain-fed wheat production is to decrease by 10–95% by 2080.

Note: *The wide ranges in temperature and precipitation reflect the scenarios on which the estimates are based across regions.*

The situation for temperate locations in the northern hemisphere is a lot more favourable. C3 crops can benefit from the CO_2 fertilization effect and crops (in most cases) are currently growing at temperature below their optimum. Low temperatures, however, are important in certain crops grown over winter because of their requirement for vernalisation. This is also a consideration in fruit tree crops in temperate climates.

Large uncertainties exist over the influence of atmospheric CO_2 concentration on crops. This CO_2 'fertilisation' effect occurs because of the plant's dependence on CO_2 for photosynthesis. Increased atmospheric concentrations can stimulate photosynthesis and improve the efficiency of water use by plants. The extent to which this happens depends on the type of plant (different plants use different photosynthetic processes) and factors such as water availability, nutrient availability and pests and diseases (Stern 2006). There are therefore complex relationships between atmospheric composition changes predicted by models and areas of increased water stress in particular (Slingo 2005). Increasing CO_2 concentration is known to have more of an effect on C3 crops (e.g., rice, wheat and soybean) than C4 crops (e.g., maize, sugarcane and sorghum). In most modelling studies, CO_2 impacts are based on controlled field experiments, which indicate that a 20 - 30 per cent rise in yield is found to occur for moderate CO_2 increases. More recent evidence, however, indicates that the effect might be much less than originally estimated, resulting in an 8 - 15 per cent increase for C3 plants and no significant change for C4 plants (Long *et al.* 2006, cited in Stern 2006).

It is also possible that other atmospheric gases, such as levels of surface ozone, could counteract some of these effects. This could be important in countries such as China where ozone concentrations are expected to rise. Crop interaction with atmospheric processes is generally not covered in large-scale modelling studies. For example, large changes in land use have been shown to have an influence over local climates, and crops themselves can have an impact on atmospheric composition (Erda *et al.* 2005).

Country-specific studies on the climate change impacts expected for the agricultural sector in most low income countries are scarce, in part due to a lack of data availability. Where country-specific studies do exist, they typically analyse a limited number of crops and cereals feature most prominently. Although such crops are important in terms of global agricultural trade, reductions in agricultural output and productivity because of climate change will affect more than just cereals. A summary of the ways in which climate change may impact agricultural production is presented in Box 1 below.

Box 1: Impact of climate change on the agricultural sector (Source: adapted from McCarl 2007).

Climate change can influence agricultural production in a number of ways. The drivers can be divided into six categories:

Temperature affects plants, animals, pests, and water supplies. For example, temperature alterations directly affect crop growth rates; livestock performance, breeding rates and appetite; pest incidence; and water supplies in soil and reservoirs.

Precipitation alters conditions such as the water directly available to crops; the drought-stress crops are placed under; the supply of forage for animals; animal production conditions; irrigation water supplies; aquaculture production conditions; and river flows supporting barge transport.

Changes in atmospheric CO_2 influence the growth of crop plants and weeds by altering one of the basic inputs for photosynthesis.

Extreme events influence production conditions; destroy trees or crops; drown livestock; alter water supplies; and influence waterborne transport and ports.

Sea level rise influences the suitability of ports and waterborne transport; inundates productive lands; and may alter aquaculture production conditions.

Climate change-motivated GHG net-emissions reduction efforts influence the desirability of production processes and the costs of inputs, plus add new opportunities.

What is known about climate change and agriculture is based on: controlled field and laboratory experiments that look at the response of crops to specific climate drivers; crop models; and large-scale models representing the global climate, agriculture and food trade systems that extrapolate into the future. A simple description of these approaches is given in Peskett 2007.

Many food crops are highly susceptible to episodes of high temperature at critical points in the growing cycle, which can result in large decreases in yield. Slingo *et al.* (2005), for example, looked at the effects of extremes of temperature on yield for wheat, groundnut and soybean and found significant decreases in yield for crops in some areas, depending on the variety. Rosenzweig *et al.* (2002) predicted that current three per cent yield losses in maize due to flooding could increase by up to six per cent due to increased climate variability and flooding (Warren *et al.* 2006).

Most large-scale climate studies model extreme events in terms of days per year that temperatures exceed a maximum threshold and the annual maximum one-day precipitation total (Slingo *et al.* 2005). Their projections indicate that extreme events such as floods and droughts could increase in both severity and frequency as a result of climate change. There is, however, little information on factors such as the timing of drought periods in relation to crop life cycles, and temporal clustering of intense weather systems. It follows that predicting the impacts of extreme events on crops through climate models is currently very difficult and poorly accounted for in most large-scale models.

A chapter of the IPCC AR4 devoted to food, fibre and forest products makes a number of important points linking climate change and food production (Easterling *et al.* 2007). This has since been updated with a number of other studies (Lobell *et al.* 2008; New *et al.* 2009) that increase the level of concern, particularly as the likelihood of global warming beyond 2^{o}C by the latter part of this century is much greater than previously thought (New *et al.* 2009; Adger and Barnett 2009). The spatial heterogeneity of impacts on productivity is important, with concerns that at low latitudes, crop productivity is projected to decrease for even small local temperature increases (1 - 2^{o}C) (Antle *et al.* 2004), and increases in the frequency of droughts and floods are projected to affect local production negatively, especially in subsistence sectors at low latitudes. Although increases in CO_2 can increase crop yields, this response decreases after the optimal temperature is exceeded and is less in open air than in chamber experiments, resulting in questions about the long-term benefit of CO_2 fertilization, given expected temperature increases and reduced soil moisture availability (Ainsworth 2008; Gifford *et al.* 2004).

Regional changes in the distribution and production of particular fish species are expected due to continued warming, with adverse effects projected for aquaculture and fisheries (Allison *et al.* 2009). Climate change impacts on food production will increase regional disparities and require significant livelihood shifts. These climatic impacts will increase the current stress that production systems already face due to degradation of key ecosystem services such as nutrient balance, water quality, and biodiversity.

2.2 Direct effects on yields: rainfed and irrigated crops

Table 4 reports the direct yield effects of the two climate change scenarios on crop yields modelled with the DSSAT suite of models for rainfed and irrigated crops in developing and developed countries, with and without CO_2 fertilization ('CF' and 'No CF'). These results are created by 'growing' each crop around the world at 0.5-degree intervals with a year 2000 climate, growing them again with a 2050 scenario value, and then calculating the ratio. In other words, no economic adjustments are included. The rainfed yield changes are driven by both precipitation and temperature changes; the irrigated yield effects are from temperature changes alone.

Table 4: The direct effects of two climate change scenarios on crop yields. (Source: Nelson *et al.* 2009).

Region	CSIRO No CF	NCAR No CF	CSIRO CF	NCAR CF
Maize, irrigated				
Developing countries	−2.0	−2.8	−1.4	−2.1
Developed countries	−1.2	−8.7	−1.2	−8.6
Maize, rainfed				
Developing countries	0.2	−2.9	2.6	−0.8
Developed countries	0.6	−5.7	9.5	2.5
Rice, irrigated				
Developing countries	−14.4	−18.5	2.4	−0.5
Developed countries	−3.5	−5.5	10.5	9.0
Rice, rainfed				
Developing countries	−1.3	−1.4	6.5	6.4
Developed countries	17.3	10.3	23.4	17.8
Wheat, irrigated				
Developing countries	−28.3	−34.3	−20.8	−27.2
Developed countries	−5.7	−4.9	−1.3	−0.1
Wheat, rainfed				
Developing countries	−1.4	−1.1	9.3	8.5
Developed countries	3.1	2.4	9.7	9.5

Note: *For each crop and management system, this table reports the area weighted average change in yield for a crop grown with 2050 climate instead of 2000 climate. 'CF' = with CO_2 fertilization; 'No CF' = without CO_2 fertilization.*

In developing countries, yield declines predominate for most crops without CO_2 fertilization. Irrigated wheat and irrigated rice have the largest decreases. On average, yields in developed countries are affected less than those in developing countries. For a few crops, climate change increases developed country yields.

In calculating these projections, the East Asia and Pacific region combines with China (which is temperate for the most part) and Southeast Asia (which is tropical). For this reason, the differential effects of climate change in these two climate zones are concealed. In China, some crops fare reasonably well because higher future temperatures are favourable in locations where current temperatures are at the low end of the crop's optimal temperature. Yields of important crops in Southeast Asia fall substantially in both scenarios unless CO_2 fertilization is effective in farmers' fields.

South Asia is particularly hard hit by climate change. For almost all crops, it is the region with the greatest yield decline. With CO_2 fertilization, the yield declines are lower; in many locations, some yield increases occur relative to 2000. However, rainfed maize and irrigated and rainfed wheat still see substantial areas of reduced yields.

Sub-Saharan Africa sees mixed results, with small declines or increases in maize yields and large negative effects on rainfed wheat. The Latin America and Caribbean region also has mixed yield effects, with some crops up slightly and some down.

2.3 Indirect effects: irrigated crops

Climate change will impact on water availability for irrigated crops. Internal renewable water (IRW) is defined in this work as the water available from precipitation. Both climate scenarios result in more precipitation over land than would occur with no climate change. Under the NCAR scenario, all regions experience increased IRW.

Under the CSIRO (Commonwealth Scientific and Industrial Research Organisation) scenario, the average IRW increase is less than occurs with NCAR (National Center for Atmospheric Research), and the Middle East and North Africa and sub-Saharan Africa regions both experience reductions of about four per cent. In addition to precipitation changes, climate change-induced higher temperatures increase the water requirements of crops. The ratio of water consumption to requirements is called irrigation water supply reliability (IWSR). The smaller the ratio, the greater the water stress on irrigated crop yields.

2.4 Regional impacts on yields and output

While not considering the full economic effects of production and consumption, Lobell *et al.* (2008) have identified crops and regions that may be 'climate risk hot spots' based on predicted yield changes due to climate change and important diet considerations. The authors identify the top five crops required for food security (based on calorie intake and population) and then synthesise results from various crop models. Probabilities are given for a range of crop yield changes. For example, 95 per cent of the models predict that climate change will, to some extent, depress yields for South Asian wheat, Southeast Asian rice, and southern African maize. These are also the 'more important' regions and crops in terms of possible threats to food security and consumption.

Table 5: Predicted changes in agricultural production across countries (Source: Cline 2007).

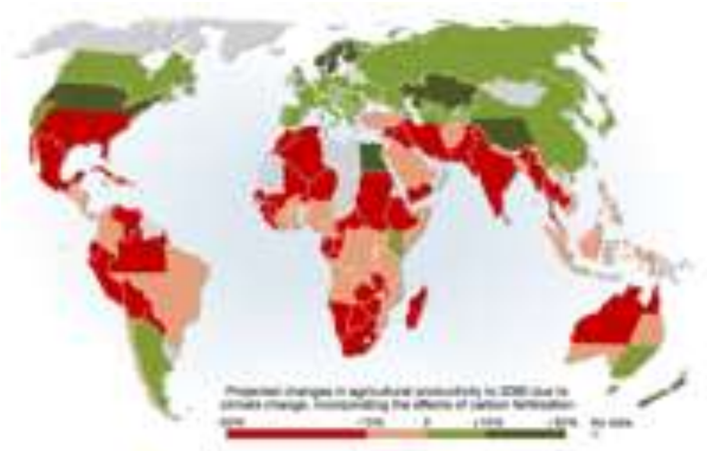
Country	Dependence on Agricultural Sector		Vulnerability to Climate Change			
	Agriculture value added (% of GDP) for nearest year	Employment in agriculture (% of total employment for nearest year)	Agricultural output for 2003		Estimated change by the 2080s in % of agricultural output	
			per ha in 2003 USD	Millions of 2003 USD	Without carbon fertilization	With carbon fertilization
Liberia	66	-	419 (c)	1 833 (c)	-32.7 (c)	-22.6 (c)
Somalia	66		-	-	-16.6 (b)	- 4.1 (b)
Guinea-Bissau	62	-	419 (c)	1 833 (c)	-32.7 (c)	-22.6 (c)
Central African Republic	56	-	478 (a)	1 429 (a)	-60.1 (a)	-54.1 (a)
Ethiopia	47	44.1	253	2 794	-31.3	-20.9
Congo, Democratic Republic of	46	-	422	3 289	-14.7	-1.9
Sierra Leone	46	-	419 (c)	1 833 (c)	-32.7 (c)	-22.6 (c)
Tanzania	45	82.1	430	4 634	-24.2	-12.8
Niger	40	-	243	1 092	-34.1	-24.2
Mali	37	41.5	350	1 644	-35.6	-25.9
Afghanistan	36	-	313	2 448	-24.7	-13.4
Malawi	34	-	267	651	-31.3	-21.0
Nepal	34	81.9	728	2 399	-17.3	-4.8
Burkina Faso	33	-	190	1 296	-24.3	-13.0
Uganda	32	69.1	280	2 015	-16.8	-4.3
Cambodia	30	70.2	378	1 438	-27.1	-16.1
Madagascar	28	78	447	1 587	-26.2	-15.1
Mozambique	28	-	253	1 123	-21.7	-10.0
Kenya	27	19	446	2 300	-5.4	8.8
Zambia	22	-	189	997	-39.6	-31
Bangladesh	20	51.7	1 355	11 421	-21.7	-9.9
Viet Nam	20	58.8	969	8 616	-15.1	-2
Zimbabwe	19	-	901	3 018	-37.9	-29
India	18	68.1	777	132 140	-38.1	-28.8
Senegal	16	-	441	1 104	-51.9	-44.7
Guinea	13	-	419 (c)	1833 (c)	-32.7 (c)	-22.6 (c)

Notes: (a) Values refer to Other Equatorial Africa (group of following countries: Republic of the Congo, Gabon, Equatorial Guinea, Central African Republic); (b) Values refer to Other Horn of Africa (group of following countries: Djibouti, Somalia); (c) Values refer to Other Equatorial Africa (group of following countries: Guinea, Guinea Bissau, Liberia, Sierra Leone).
Sources: Cline (2007); World Development Indicators for nearest year.

The *Stern Review* (2006) also highlights that impacts are expected to be strongest across Africa and western Asia, where yields of the dominant regional crops may fall by 15 - 35 per cent once temperatures rise by 3 or 4ºC. Sub-Saharan Africa is expected to be worst affected, meaning the poorest and most food insecure region is also expected to suffer the largest contraction of agricultural production and income. Despite the uncertainties regarding short-term effects, models do point to many cases where food security is clearly threatened by climate change by 2030, with losses in major crops by this time (Lobell *et al.* 2008).

Cline (2007) however focuses on agricultural output rather than changes in yields and provides the most comprehensive estimates available of aggregate changes in output; these have been used and supplemented by the contribution of the agricultural sector to GDP and employment for the low income and less developed countries included, and the results are summarised in Table 5. Cline's 2007 estimates are based on a consensus set of geographically detailed estimates for changes in temperature and precipitation by the 2080s, which are applied to agricultural impact models. Mapped results are shown in Figure 1.

Figure 1: **Projected losses in food production due to climate change by 2080 (Source: Cline 2007).**



Based on a consensus estimate of six climate models and two crop modelling methods, Cline (2007) concluded that by 2080, assuming a 4.4ºC increase in temperature and a 2.9 per cent increase in precipitation, global agricultural output potential is likely to decrease by about 6 per cent, or 16 per cent without carbon fertilization. Cline suggested a range of output potential decline between 10 and 25 per cent among regions. As climate change increases, projections have been made that by 2080 agricultural output potential may be reduced by up to 60 per cent for several African countries (on average 16 - 27 per cent) dependent upon the effect of carbon fertilization. These effects are in addition to general water scarcity because of melting glaciers, change in rainfall patterns, or overuse.

2.4.1. Africa: summary of impacts

The science of the changes in climate expected in Africa has been discussed recently in Conway, 2009. The executive summary highlights:

- The drier subtropical regions will warm more than the moister tropics.
- Northern and southern Africa will become much hotter (as much as 4°C or more) and drier (precipitation falling by 15 per cent or more).
- Wheat production in the north and maize production in the south are likely to be adversely affected.
- In eastern Africa, including the Horn of Africa, and parts of central Africa, average rainfall is likely to increase.
- Vector-borne diseases such as malaria and dengue may spread and become more severe.
- Sea levels will rise, perhaps by half a metre, in the next fifty years, with serious consequences in the Nile Delta and certain parts of West Africa.

The factsheet on sub-Saharan Africa produced by the International Food Policy Research Institute, *Climate Change: Impact on Agriculture and Costs of Adaptation* (Nelson *et al.* 2009), made the following findings:

1. African countries are particularly vulnerable to climate change because of their dependence on rainfed agriculture, high levels of poverty, low levels of human and physical capital, and poor infrastructure.
2. The negative effects of climate change on crop production are especially pronounced in sub-Saharan Africa, as the agriculture sector accounts for a large share of GDP, export earnings, and employment in most African countries. Furthermore, the vast majority of the poor reside in rural areas and depend on agriculture for their livelihoods.
3. The crop model indicates that in 2050 in sub-Saharan Africa, average rice, wheat, and maize yields will decline by up to 14 per cent, 22 per cent, and 5 per cent, respectively, as a result of climate change.
4. Irrigation water supply reliability – the ratio of water consumption to requirements – is expected to worsen in sub-Saharan Africa due to climate change.
5. Without climate change, calorie availability is expected to increase in sub-Saharan Africa between 2000 and 2050. With climate change, however, food availability in the region will average 500 calories less per person in 2050, a 21 per cent decline.
6. In a 'no climate change' scenario, only sub-Saharan Africa (of the six regional groupings of developing countries studied in the report) sees an increase in the number of malnourished children between 2000 and 2050, from 33 to 42 million. Climate change will further increase this number by over 10 million, resulting in 52 million malnourished children in 2050.
7. Additional investments to increase agricultural productivity can compensate for many of the adverse effects of climate change. Sub-Saharan Africa needs 40 per cent of the estimated 7 billion US$ per year in additional global agricultural investments, the majority of that for rural roads.

2.4.2. Asia: summary of impacts

The following highlights are taken from *Climate Change: Impact on Agriculture and Costs of Adaptation* (Nelson *et al.* 2009).

1. The Asia-Pacific region will experience the worst effect on rice and wheat yields worldwide, and decreased yields could threaten the food security of 1.6 billion people in South Asia.
2. In South Asia, average yields in 2050 for crops will decline from 2000 levels by about 50 per cent for wheat, 17 per cent for rice, and about 6 per cent for maize because of climate change.
3. In East Asia and the Pacific, yields in 2050 for crops will decline from 2000 levels by up to 20 per cent for rice, 13 per cent for soybean, 16 per cent for wheat, and 4 per cent for maize because of climate change.
4. Average calorie availability in Asia in 2050 is expected to be about 15 per cent lower, and cereal consumption is projected to decline by as much as 24 per cent compared with a 'no climate change' scenario.
5. In a 'no climate change' scenario, the number of malnourished children in South Asia would fall from 76 to 52 million between 2000 and 2050, and from 24 to 10 million in East Asia and the Pacific. Climate change will erase some of this progress, causing the number of malnourished children in 2050 to rise to 59 million in South Asia and to 14 million in East Asia and the Pacific, increasing the total number of malnourished children in Asia by about 11 million.
6. To counteract the effects of climate change on nutrition, South Asia requires additional annual investments of 1.5 billion US$ in rural development, and East Asia and the Pacific require almost 1 million US$ more. Over half of these investments in both regions must be for irrigation expansion.

Additional facts:

- The Asian countries most vulnerable to climate change are Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar and Nepal.
- Afghanistan, Bangladesh, India and Nepal are particularly vulnerable to declining crop yields due to glacial melting, floods, droughts and erratic rainfall, among other factors.
- Asia is the most disaster-afflicted region in the world, accounting for about 89 per cent of people affected by disasters worldwide.
- More than 60 per cent of the economically active population and their dependents – 2.2 billion people – rely on agriculture for their livelihoods in developing parts of Asia.

(Source: Asian Development Bank 2008.)

2.5 Agricultural systems and livelihoods

Agriculture in most developing countries is important for food security in two ways: it produces the food people eat and it provides the primary source of livelihoods for two-thirds of the working population in sub-Saharan Africa (ILO 2008). If agricultural production in the low-income developing countries is adversely affected by climate change, the livelihoods of large numbers of the rural poor will be put at risk and their vulnerability to food insecurity increased. Much of the following discussion and examples are based on an FAO report on food security (2009).

In general, Africa's crop and livestock systems have evolved based on the availability and opportunities provided by the natural resource base, in addition to market systems (Morton, 2007). Farms tend to be small, under traditional or informal tenure, with diverse soil types and individual farmer management strategies. Padgham (2009) notes that vulnerability to the extreme events of climate change is determined by: the extent of abiotic and biotic stresses in the production system; the ownership of land and livestock; land size and productivity; access to credit and markets; availability and affordability of agricultural inputs; access to cash income from off-farm livelihood activities; the state of village infrastructure; gender of household head; and connection to family and social networks. These factors determine the sensitivity of household livelihoods to variations in productivity and climate, and their capacity to respond to these impacts.

In the arid and semi-arid zones of Africa are an estimated 50 million pastoralists and agro-pastoralists who constitute one of the poorest and most vulnerable population sub-groups (Rass 2006). Pastoralists obtain more than 50 per cent of their total gross income from mobile livestock-rearing on communal pastures; agro-pastoralists obtain between 25 per cent and less than 50 per cent from livestock, and more than 50 per cent from cropping activities (Swift 1988). In addition, the low but highly variable rainfall patterns and poor soils; the risks of epidemic diseases; exclusion from livestock export markets due to insufficient health standards; risks of violent conflict over natural resources; decreasing rangelands with increasing human and livestock populations; and widespread marginalization further elevate their vulnerability to the potential impacts of climate change (Rass 2006). The changes to crop production, availability of feed crops, and grazing systems will have negative and permanent impacts on animal husbandry and the free-range grazing of livestock.

Although pastoralists have developed resilient livelihood systems to deal with their harsh and unpredictable environment, the new dynamics introduced by global climate change will amplify potential impacts. The main factor in pastoral strategies, for example, is livestock mobility, i.e., moving herds to areas with better grazing conditions and securing access to critical resources during the dry season and in times of crisis (Hesse and Cotula 2006). With climate change, the number, distribution and productivity of permanent pastures and water points – which are so critical for livestock survival during the dry season – are bound to decline.

Dry lands used for grazing are fragile ecosystems that are increasingly being degraded, yet they are also very resilient towards disturbances (Janzen 1988). The greatest danger is the potential to increase desertification because of resource management inefficiencies (Gonzalez 2001). Recent droughts in Africa illustrate the potentially large effects of local and/or regional climate variability on livestock (IPCC 2007). One obvious consequence would be rangeland degradation involving reduced forage productivity and quality, and lack of resilience to drought, which could lead to massive livestock loss (FAO 2008a).

2.6 Food security

Agricultural production and food security in many developing countries and regions are likely to be severely compromised by climate change and climate variability (IPCC 2007). Currently, most African countries are net importers, with over 50 per cent of North Africa's food requirement and between 25 per cent and 50 per cent in sub-Saharan Africa imported (FAO 2008b).

Extreme events, such as droughts and floods, impact on crop and livestock productivity as well as impacting on access to food. If infrastructure is impacted by heat stress on roads or through increasing flood events that destroy bridges, roads and railways, then distribution of food is hampered. When infrastructure is destroyed by floods this also impedes people's access to markets to sell or purchase food.

FAO (2008b) defines the four main components of food security as: food availability, food accessibility, food utilisation, and food system stability – which implies affordability. Climate change will affect all the four dimensions of food security. The impacts of climate change on food availability will be experienced differently, depending on location (as discussed). Warming of more than 3ºC is expected to have negative effects on production in all regions (IPCC 2007). The supply of meat and other livestock products will be influenced by crop production trends, as feed crops account for roughly 25 per cent of the world's cropland (FAO 2008b). The IPCC Working Group II also has a good introduction to the topic of food security in a case study in the Africa Chapter (9).

Food accessibility is a measure of the ability to secure entitlements, which are defined as the set of resources (including legal, political, economic and social) that an individual requires to access food. Food accessibility for many people in developing countries remains closely tied to local food production (FAO 2008a, 2008b; Bruinsma 2009). The *World Development Report 2008* stresses the importance of agriculture-led growth to increase incomes and reduce poverty and food insecurity in the least developed and developing countries. Countries with large food insecure populations are often also those whose agricultural systems are highly vulnerable to climate shocks now, particularly in sub- Saharan Africa and South and Southeast Asia (Gregory *et al.* 2005). Climate change will affect food accessibility by influencing food allocation. Food is allocated through markets and non-market distribution mechanisms. For rural communities in Africa that produce a substantial part of their own food, and also non-farming low-income rural and urban households, climate change impacts on food production may reduce availability to the point that allocation choices have to be made within the household (Medany *et al.* 2006). Climate change will also affect affordability (by affecting income) and also the ability of people to choose the food they want to eat (known as preferability) (FAO 2008b).

Food utilisation refers to the use of food and how a person is able to secure essential nutrients from the food consumed. Climate change will cause new patterns of pests and diseases to emerge, affecting plants, animals and humans, and posing new risks for food security, food safety and human health. Increased incidences of water-borne diseases in flood-prone areas, changes in vectors for climate-responsive pests and diseases, and the emergence of new diseases could affect both the food chain and people's physiological capacity to obtain necessary nutrients from the food they eat. Food system stability is determined by the temporal availability of, and access to, food. Droughts and floods are particular threats to food stability and are expected to become more frequent, more intense, and less predictable as a consequence of climate change.

Africa's poor agricultural incentives and infrastructure, inadequate trade and pricing policies, and weak capacity signify low investments in this sector, although more than 60 per cent of its population depends directly on agriculture and natural resources (FAO 2003). With farming done mainly under rainfed conditions, increasing land degradation and low levels of irrigation, i.e., six per cent in Africa compared to 38 per cent in Asia (FAO 2005), climate change can significantly reverse the progress towards poverty reduction and food security.

2.7 Non-production impacts of climate change

This subsection introduces the impacts of climate change on non-production aspects of agriculture, touching mainly on market access, labour and wages, health, institutional arrangements, investments and technology, incentives to save or consume income, national policy orientation and intervention capacity, international aid, and migration (amongst many others) (S. Lambat, pers. comm., 2011). Cutting across these potential impacts are also important factors such as access to information, participation and empowerment, access to rights and equity concerns, and potential impacts on marginalised groups.

In order to assess these many interconnected non-production effects of climate change on agriculture, an economic perspective has been chosen, which will help to structure these effects according to different impacts on market access and competitiveness, influenced by factors such as access to information, cost of labour, institutional arrangements, government assistance, investment capacity, and access to information, amongst other influences. All the factors below are interlinked and influence one another.

They can also be assessed according to whether they are internal or external to a system. Given the heterogeneous and complex nature of agriculture, and the fact that it needs to be approached from a local perspective (assessing local needs, as opposed to a sectoral approach), it is relevant to look at the impacts of climate change on farming systems.

In the FAO classification of the farming systems in developing countries, there are 72 systems that cover eight broad categories, according to the available natural resource base, dominant pattern of farm activities, and household livelihoods (including their relationship to markets and the intensity of their production activities):

1. Irrigated farming systems.
2. Wetland rice-based farming systems.
3. Rainfed farming systems in humid areas.
4. Rainfed farming systems in steep and highland areas.
5. Rainfed farming systems in dry and cold low potential areas.
6. Dualistic (mixed large commercial and smallholders) farming systems.
7. Coastal artisanal fishing systems.
8. Urban-based farming systems.

A farming system has internal and external influences that determine the relationship of farming systems to markets. According to Dixon *et al.* (2001) some internal influences are savings and investments, consumption, and sales. These determine consumption decisions, with savings and investments also influencing production decisions. Household, processing and off-farm work influence production decisions. External factors influencing the system are markets, policies, institutions, public goods, and information.

Other factors are on the border of the farming system, between internal and external factors; these are mainly technology and resources, which can be imported and transferred from one system or entity to another. Certain influences, listed as internal, can also be external, depending on the system (core production, involvement and influence of stakeholders, and international influence on the system, amongst other elements). Hence, we have listed some potential influences on farming systems below, without clearly defining whether they are internal or external.

2.7.1 Physical access and infrastructure

Access to markets is driven by infrastructure and the cost of transportation. Intensity and frequency of natural disasters can lead to damaging infrastructure, and hence the cost of transportation can rise as a result. This in turn can also lead to a raise in the final price of goods.

Infrastructure at a particularly high risk from climate change includes that related to water, energy, transport, buildings and telecommunications. From the point of view of market access and the price competitiveness of agricultural products, water, energy and transport seem to be the most directly-affected sectors.

Potential increased frequency of extreme daily rainfall events may affect the capacity and maintenance of storm water, drainage and sewer infrastructure. Significant damage costs and environmental spills are likely if water systems are unable to cope with extreme or multiple events in a season. 'Acceleration of the degradation of materials and structural integrity of water supply, sewer and storm water pipelines may occur through increased ground movement and changes in groundwater. Water shortages may occur due to greater demand for water associated with increased temperatures, reduced available moisture and increased population.' (CSIRO 2007). Decreased annual rainfall is also likely to affect water supply. Any costs associated with climate change damages are likely to be passed on and borne by water users, most probably through price increases. In turn, the prices of products that use large amounts of water will increase.

Electricity is one of the most costly expenditures for the populations of rural areas in developing countries. Electricity costs may rise as power supply infrastructure and services incur damages caused by more frequent and violent storms. 'Increased wind and lightning could damage transmission lines and structures while extreme rainfall events may flood power substations. Coastal and offshore gas, oil and electricity infrastructure is potentially at risk of significant damage and increased shut-down periods from increases in storm surge, wind, flooding and wave events, especially when combined with sea level rise.' (CSIRO 2007).

Transport may become more difficult as flood damage to roads, rails, bridges, airports, ports and tunnels is caused by an increasing frequency and intensity of extreme rainfall events. 'Rail, bridges, airports and ports are susceptible to extreme wind events; ports and coastal infrastructure are particularly at risk when storm surges combine with sea level rise. Ground movement and changes in groundwater may also accelerate the degradation of materials, structures, and foundations of transport infrastructure. Materials, such as asphalt on roads, tarmac at airports, or steel in bridges and rail tracks, can also experience significant stress as temperatures and solar radiation increase. Increased temperature causes expansion of concrete joints, protective cladding, coatings and sealants on bridges and airport infrastructure.' (CSIRO 2007). This is particularly detrimental to domestic and international market access, especially when a country is land-locked or when there are few resources to pay for transportation.

In developing countries, traditional transportations systems are often used to access local markets in rural areas. Impacts of climate change on health of cattle are therefore also an important factor in this context, as they are also used in production systems.

2.7.2 Labour/workforce

Agriculture in developing countries is labour intensive. Cattle are also important in the production process; hence their health and cost influence prices. 'Diseases transmitted by vectors (insects, ticks, molluscs, rodents, bats, etc.) are highly susceptible to environmental change, as are those for which wildlife acts as a reservoir (avian influenza, bovine tuberculosis, African swine fever, etc.)' (Agricultural Research for Development 2009).

There are three main areas where climate change can impact labour: health, wages, and migration. The efficiency and availability of labour should determine the cost of labour, which in turn determines the price of the final product.

Changes in weather, food availability, increase in the frequency of extreme events, and sea level rise have contributed to migration and displacement of population (temporarily in most cases). In certain areas, the availability of labour may be reduced. This could be an opportunity for workers that could increase their wages, though often, this does not happen as the need for employment determines the wage, which can also be exacerbated by the efficiency of labour.

The efficiency of labour is also determined by the availability of natural resources needed in the production process. Climate change may impact on the time and the size of workforce necessary to source certain natural resources in the future. Other considerations, such as the qualifications of workers needed and unemployment rates, influence both wages and final prices. Finally, wages also determine the purchasing power of local communities.

Health is one of the major concerns: 'Ongoing and future climate change will lead to higher heat exposures for billions of people in tropical countries, and most likely affect poor people in labouring occupations particularly, adding to the health inequities caused by the other health hazards linked to climate change.' (Kjellstrom 2009).

In agriculture, workers are particularly exposed to heat, which is likely to increase with climate change. Productivity is a function of comfort and of physiological limits (heat stress indices have been developed, some based on comfort and others on physiological limits of the human body, see Parsons, K., 2003, note (7) in Kjellstrom 2009).

For example, agricultural workers in El Salvador and Nicaragua cut sugar cane with a machete in the sun for 6 - 8 hours every day during a 3 - 5 month harvest. Younger workers have a high rate of chronic kidney disease, often fatal. One of the causes is daily dehydration due to heat and sweating without sufficient drinking water supply in the farm fields. Climate change impacts are likely to force us to find solutions to productivity levels by assessing physiological limits and comfort levels for productive work.

2.7.3 Investment capacity and access to technology

Capacity to invest can also be altered by climate change impacts, especially for those with few resources. If a sector requires investments then this would mean that in order to recover initial investments, or anticipate future ones, prices would have to rise. Investment capacity, and hence ability to maintain prices at competitive levels, depends on savings, availability of credit mechanisms and other institutional arrangements (mainly the establishment of property rights), state support, international aid, and other pull factors that influence international investments and technology transfer.

Other elements also determine incentives to invest: monetary value, political stability, and uncertainty. There may not be much incentive to invest if the stability of a region is undermined, which can also be the case due to climate change. Moreover, the value attributed to local currency can also influence incentives to invest, save, or consume income.

Access to technology plays a crucial role in production output, quality, and adaptive capacity. Often, developing countries have poor access to technology. Incentives for private entities, governmental and institutional accountability should be prioritised to transfer hard and soft technologies, as well as involving stakeholders in capacity building in this area.

Table 6: Some of the most pressing technology needs for adaptation in agriculture (Source: ICHRP 2011).

Crop management	Need for crop varieties resistant to expected changes
Efficient irrigation and water conservation	Need for technologies and strategies for efficient water utilisation (such as drip irrigation, improved networks of reservoirs, and treadle pumps)
Land management	Need for techniques and practices that include terracing and stabilisation of slopes, application of minimum or no tillage, probes for measurement of soil moisture, and changing practices to conserve soil moisture and nutrients
Meteorological observation and monitoring equipment	Need for observation and monitoring equipment, as well as efficient mechanisms for diffusion of information

2.7.4 State intervention and adjustment policies

Subsidies and other government assistance schemes can influence prices, and hence the incentives to invest in goods and services, and their competitiveness. Targeted interventions and subsidies may also promote certain activities with spillover effects in other domains – for example in the context of research and development.

However, state capacity to intervene can be hindered by climate change, mainly due to lower income from taxes and higher government expenditure, particularly when the production of a good has a large share in export income, as is often the case for agriculture in developing countries.

The state must also have the capacity to intervene – not only financially, but also in terms of coordinating its interventions. This may be difficult due to the lack of capacity in certain developing countries, and given the uncertain nature of climate change impacts that make it difficult to plan and coordinate interventions in advance.

Finally, the distribution of the gains of state intervention to losers of these policies should also be taken into consideration when looking at the non-production effects of climate change on agriculture, as this influences purchasing power and unemployment rates amongst other things.

2.7.5 Institutional arrangements

The establishment of property rights and access to credits are important factors in influencing investments, which in turn determine prices.

In developing countries, a large proportion of the population working in agriculture does not have access to land ownership. Sea level rise and other extreme weather events may further erode whatever land-use rights do exist, particularly for marginal groups. Migration may also have important and unclear effects in this area.

A lack of credit, needed by rural households for investing in agriculture and smoothing out seasonal fluctuations in earnings, may become increasingly limited as climate change impacts result in a decreasing availability of resources. This effect may spill over to other areas of rural livelihoods, since cash flows and savings in rural areas for the majority of households are small, and rural households typically tend to rely on credit for other consumption needs like education, food, housing, and household functions.

Already fragile institutions in this area may be less prone to taking risks due to aggravated and more frequent climate-induced pressures. For many in the agricultural sector in developing countries, access to credit is crucial – first for production, and then in helping to build longer-term adaptation strategies.

2.7.6 Purchasing power

Purchasing power can be assessed from both sides: production and consumption. Producers need to be able to purchase materials required to produce their goods, as well as access natural resources needed in this process. Climate change can impact both, and hence influence the price of final products. This is particularly pronounced in cases where materials need to be imported. The purchasing power of producers also affects investments in means to raise productivity, which also may affect the price of final products.

The purchasing power of consumers is also important in determining the price. For instance, if climate change uncertainty leads the average consumers to save, or if average purchasing power has dropped, prices need to be adjusted accordingly. This in turn can affect the purchasing power of producers who would, in normal circumstances, sell their products at a higher price.

Climate change can thus have important effects on purchasing power and on consuming/saving averages. Firstly, the uncertain climate induced by environmental pressure and more frequent weather events may induce a higher proportion to save, resulting in a lower consumption rate. Secondly, the impoverishment of people due to climate-induced pressures is also likely to affect consumption rates. Other considerations include the elasticity of the supply and demand for a particular product, as well as how climate change impacts the proportion of the household budget spent on agricultural goods.

2.7.7 Access to information: uncertainty and insecurity

Information has powerful effects and influences all parties: production, consumption, and third parties (such as governments and institutions). Information can create, adjust or distort incentives to produce, to consume, to invest and to save, amongst others. Access to information helps all actors foresee who is going to adapt to what, and hence take measures knowing the likely actions of other agents.

With an influence on many areas, information, degrees of uncertainty and insecurity, and risk aversion of agents, all can directly or indirectly determine the price of a final product, and hence its competitiveness.

Some information that could be helpful for agriculture in the context of climate change (but also generally) concerns climate predictions, soil quality, technologies, and prices. Information can be made available through different media, with a focus on those that have best coverage in rural communities, such as the radio.

Price information about agricultural commodities traded in local and regional markets is important to ensure transparency. Many programmes are making efforts towards promoting transparency in the marketplace; the Jamaican Ministry of Agriculture and Fisheries (MOAF) has launched the Jamaica Agriculture Market Information System (JAMIS), which provides up-to-date information online, and is designed to enable producers, purchasers, consumers and distributors to make more informed decisions about the sale and purchase of their produce. As explained by the Minister of Agriculture and Fisheries, the Hon. Dr Christopher Tufton: 'This data will assist the sector by providing the tools to determine where and when to buy and sell produce. It will also assist farmers to plan their production and promote a transparent marketplace, by putting buyers and sellers on a more equal bargaining basis.' In addition to publishing the prices in local newspapers, JAMIS is planning to publish weekly prices on notice boards in main municipal markets and Rural Agricultural Development Authority (RADA) parish offices. A text messaging service is to be made available (Mattioli 2010).

2.8 Economic impacts of climate change

This subsection has discussed the complex ways in which climate change impacts on agriculture and food security. As well as direct effects on productivity, climate change affects agriculture through indirect effects on irrigation, and through the non-productive components of agricultural systems, such as infrastructure and the workforce.

A body of literature has built up on the economic implications of these impacts at the national, continental and regional levels (see Table 7 for examples of such studies). This literature has often struggled to incorporate the complexities of climate change impacts on agriculture and food security, and has largely remained focused on impacts on crop production. Nevertheless, these studies do have an important role to play in highlighting the likely type and scale of economic impacts, and the need for adaptation to reduce these effects.

Table 7: Selected studies of economic impacts of climate change on agriculture.

Name	Topic	Methodology (including how they dealt with adaptation)	Conclusion
Reid *et al.* 2007	The economic impact of climate change in Namibia	Looked at the impacts of climate change on agriculture and fisheries, and then used a CGE model to model possible general equilibrium effects. Assumed no adaptation.	Climate change will cause a fall in GDP of around 1-6% (£35- £100 million), if no action is taken.
Bezabih *et al.*2010	The economic impacts of climate change-induced adjustments on the Tanzanian economy	Used a country-wide dynamic CGE model (an extension of the IFPRI model) to model the impact of climate change on agriculture and the feedbacks between agriculture and other sectors, under two Total Factor Productivity and climate change and no-climate change scenarios.	Climate change will impact little on agricultural productivity until 2030, but then more. By substituting factors, the overall impacts can be quite limited, suggesting a need for autonomous adaptation and policies to strengthen the overall economy, rather than direct adaptation policies.
Kurukulasuriya and Mendelsohn 2006	The impacts of climate change on net revenue per hectare across Africa (based on 11 country studies)	Ricardian method making use of crop response simulation modelling. Used regression to determine how different climatic variables affect net revenue per ha, then looked at impacts of two types of climate change scenarios.	Impacts vary considerably depending on scenario, e.g., sectoral gains of $97 billion p.a. under one model, and losses of $48 billion p.a. by 2100 under another. Dryland farming is likely to be impacted most negatively.
Cline (2007)	The impact of climate change on agriculture through the 2080s for over 100 countries	Combined the Ricardian and crop process model approaches, using large amounts of geographical and climatic detail for more than 100 countries and regions. He chooses a 'consensus', rather than looking at a wide range of values.	Global agricultural productivity will decline by about 3% by 2080 with carbon fertilisation, or by about 16% if carbon fertilisation does not occur. The impact will be uneven, with developing countries feeling the losses disproportionately.
Caldazilla *et al.* 2009	Economy-wide impacts of climate change on agriculture in sub-Saharan Africa	Used a partial equilibrium model with a water simulation model (IMPACT), and a general equilibrium model including water resources (GTAP-W), to look at the impact of climate change under two adaptation scenarios (doubling irrigated areas and increasing crop production by 25%), compared with a baseline of no specific adaptation.	Without adaptation, climate change will cause a 1.6% fall in food production, with heavy losses in sugar cane (10.6%) and wheat (24.1%). An increase in agricultural productivity achieves better outcomes than an expansion of irrigated areas. Both scenarios lead to lower world food prices.

Name	Topic	Methodology (including how they dealt with adaptation)	Conclusion
Caldazilla *et al.* 2010	Potential impacts of climate change and CO_2 fertilisation on global agriculture	Used a new version of the computable general equilibrium GTAP-W model, which implements water as an explicit factor of production for irrigated agriculture. Assessed how climate change, modelled under two climate change scenarios, affects water availability and thereby worldwide agricultural production in two time periods (the 2020s and the 2050s). They use six scenarios, including CO_2 fertilisation and distinguishing between rainfed and irrigated land.	Global food production is expected to fall by around 0.5% in the 2020s and 2.3% in the 2050s. Higher market values are expected for all crops, and in particular cereals, grains, sugar cane, sugar beet and wheat (between 39-43% depending on scenario). Countries are affected by changes in competitiveness as well as by regional climate change.
De Bruin *et al.* 2009	Climate change costs as % of output	Explicitly includes adaptation in an Integrated Assessment Model (Nordhaus and Boyer's 2000 DICE model), which sees net damages as the total of the residual damages and the protection costs. They considered four scenarios of different balances between adaptation and mitigation.	Both mitigation and adaptation can reduce the impacts of climate change; adaptation by (on average) 33%. Adaptation is the main climate change cost-reducer until 2100, then mitigation becomes more important.
Deressa 2007	The economic impact of climate change on Ethiopian agriculture	Ricardian approach that captured farmers' adaptations – analysed data from 11 of the country's 18 agro-ecological zones and surveys 1000 farmers. They regressed net revenue against climate, household and soil variables, carried out a marginal impact assessment of increasing temperature and precipitation, and examined the impact of uniform climate scenarios on net revenue per hectare.	Increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture.
Kurukulasuriya and Mendelsohn 2008	The impacts of climate change on agriculture in Africa	Develops an Agro-Ecological Zone (AEZ) model. Calculated the average per cent cropland and the average crop net revenue for each AEZ. Assessed how cropland and crop net revenue will change under two climate change scenarios, as farms shift between zones.	Cropland changes little under either climate scenario, but crop revenue ranges from a loss of 14 per cent in the mild climate scenario to 30 per cent in the harsher climate scenario. The central region of Africa is hurt the most.

2.9 Conclusion

A brief summary of the main impacts and elements of climate change on global agriculture has been presented. Climate change poses considerable challenges to food security. Adapting food systems both to enhance food security for the poor and vulnerable and to prevent future negative impacts from climate change will require attention to more than just agricultural production, as laid out in the discussions of food security and non-production impacts, above. Food security can only be ensured and enhanced with a range of interventions across activities and agricultural systems – ranging from production to distribution and allocation – informed through knowledge of systems and impacts.

3. Previous work on costing climate change adaptation in agriculture

Section 2 has discussed the complex ways in which climate change impacts on agriculture and food security – through direct and indirect effects, as well as through its impacts on the non-productive components of agricultural systems. Although economic estimates of the impact of climate change on agriculture often struggle to incorporate this complexity, a broad range of studies on this topic (see Table 7) indicate that these impacts are likely to be substantial. Adaptation has an important role to play in reducing the adverse effects of these impacts.

In order to plan for this, decision makers at both the national and sub-national levels, as well as the international level, require information about the costs of adaptation. This allows an assessment of both the relative cost-effectiveness of specific adaptation measures on the ground, and international financing needs.

While this study focuses on the costs of adaptation measures, it is important to consider these in the context of the total costs of climate change; these costs include those of mitigation and adaptation as well as the residual impacts – the damages which are not prevented through either mitigation or adaptation – and can, to a certain extent, be substituted for each other. For example, by increasing the amount of mitigation we undertake we may reduce the need for adaptation, or it may make more sense to choose to accept the residual costs rather than adapt to a specific climate change impact – e.g., taking an area of land out of production rather than installing a costly irrigation system.

Any decision about which path to pursue must be based on reliable information about these costs. Section 3 discusses the methodologies and results of previous studies costing adaptation. It highlights gaps in the existing literature and draws out key learning points for this study and future ones that aim to cost agricultural adaptation.

3.1 Impact studies

Although it is only in recent years that formal economic assessments of adaptation have been published, a body of knowledge surrounding adaptation had begun to build up prior to this. Tol *et al.* highlighted in 1998 that at that time most of the material on the costs and benefits of adaptation had been collected in the context of impact analysis, and impact studies – such as those in Table 7 – have remained closely associated with the adaptation literature since. In particular, although these do not aim to address the specific costs of adaptation, they often include some adaptation costs, found, in a survey of early impact studies, to make up around 7 - 25 per cent of total impact costs (Tol *et al.* 1998).

Impact studies can be classified as: those that take a Ricardian approach; those based on coupled agronomic and economic models; those based on hedonic equations; and those based on the concept of an agro-ecological zone. Although they face common challenges, including the need to take into account indirect effects on agriculture as well as direct effects on production, (as discussed in Section 2), there are advantages and disadvantages to each, with each incorporating adaptation in different ways.

The **Ricardian model** analyses a cross-section of farms under different climatic conditions and examines the relationship between the value of land or net revenue and agro-climatic factors (Mendelsohn *et al.* 1994; Sanghi *et al.* 1998; Kumar and Parikh 1998; Polsky and Esterling 2001). Studies are country-specific and show a diverse array of effects, with some countries, such as the US, benefiting and others losing (Sanghi and Mendelsohn 2008). The most important advantage of the Ricardian model is its ability to incorporate private adaptations. Farmers adapt to climate change to maximise profit by, for example, changing the crop mix, changing the dates of planting and harvesting, and following a host of agronomic practices. The farmers' response involves costs, causing economic damages that are reflected in net revenue. Thus, to fully account for the cost or benefit of adaptation, the relevant dependent variable should be net revenue or land value (capitalised net revenues), and not yield. Accordingly, the Ricardian approach takes adaptation into account by measuring economic damages as reductions in net revenue or land value induced by climatic factors. The other advantage of the model is that it is cost-effective, since secondary data (climatic, production and socioeconomic factors) on cross-sectional sites can be relatively easy to collect (Deressa and Hassan 2009). However, Ricardian approaches have been criticised for ignoring price changes and failing to control for other factors that affect farm income (Mendelsohn and Dinar 1999).

The **agronomic-economic model** approach models how a climate change impact projected by an agronomic model, such as decreasing land productivity or yields in agriculture, impacts on the economy – in the case of CGE models, through general equilibrium effects. It is capable of capturing complex economy-wide effects of exogenous changes while at the same time providing insights into micro-level impacts on producers, consumers and institutions (Oladosu *et al.* 1999; Mabugu 2002). However, agronomic modelling approaches tend to exclude the possibility of farmer adaptation and therefore may overestimate the damages caused by climate change (Mendelsohn and Dinar 1999).

The use of **hedonic equations** assumes that the impacts of climate change on profitability will be capitalized into the value of land and yields. An equation relating land values to climate variables is estimated and used to forecast the impact of changes in these variables on land values over a number of different climate change scenarios (e.g., Schlenker *et al.* 2005). They have the advantage of not being constrained by the adaptation strategies that are deemed feasible by the parameterisation of the models used in a simulation approach. Deschenes and Greenstone (2007) note that the hedonic approach is subject to criticism because unobserved factors which influence land values are excluded from the hedonic equation. As a result it is probable that the estimates which result from this approach are biased. They therefore propose an alternative approach in which profitability is directly related to climatic variables. They note that this may also produce biased results because it fails to take into account the full extent to which farms may adapt to climate change, but argue that because the direction of bias is known (an under-estimate of the impacts), their method is superior to the hedonic approach.

Agro-ecological zone studies assume that when agro-ecological zones (AEZs) shift due to climate change, agriculture will change to resemble that currently seen in the zone the area shifts into. As these studies are based on potential attainable yields rather than those achieved in reality, AEZ studies may overestimate the gains obtained by autonomous adaptation (ABDI), and may, in particular, overestimate the productivity gains expected in the high latitudes (Cline 2007).

These different approaches have complemented each other in contributing to our understanding of the economic impacts of climate change, and the need for adaptation. However, as Tol *et al.* (1998) argue, the ways impact studies incorporate adaptation – including either no adaptation, an arbitrary level of adaptation, adaptation based on an observed spatial or temporal analogue, or modelled adaptation – are generally not very realistic. For example, the analogues used in Ricardian studies such as Mendelsohn *et al.* (1994) assume that future farmers have similar motives and constraints as present day farmers, whereas in reality influences such as food markets and policies are likely to change. Modelled adaptation measures may fail to incorporate the complexities of the climate change impacts discussed in Section 2 – e.g., devising responses to linear climatic changes such as average annual temperature, rather than modelling responses to changes such as increased magnitude or frequency of storms or seasonal shifts – and often assume farmers have perfect knowledge about the options available to them. Additionally, impact studies tend to include costs associated with a new equilibrium position (for example, growing a new crop variety) without incorporating the transition costs (such as a change of equipment) required to get there.

These constraints, as well as the fact that impact studies generally do not separate the costs of adaptation from other costs brought about by climate change, limit the extent to which they are useful in understanding the costs of adaptation. However, they continue to inform our understanding of the need for adaptation and the type of benefits likely to be accrued, and as such provide an important background for studies aiming to cost adaptation.

3.2 Costs of adaptation

3.2.1 Individual adaptation options

The past few years have seen a number of attempts to explicitly cost adaptation. The earliest of these ascribed costs to single, specific adaptation measures. For example, the cost of developing new crop varieties in public breeding programmes has been put at US$2.1 million for oats and $2.8 - 3.0 million for wheat for a single variety (NRC 2000). The Alliance for a Green Revolution in Africa puts the cost of developing 200 new crop varieties better adapted to local environments at $43 million. The development of Bt maize by Monsanto is thought to have cost US$10 - 25 million (NRC 2000). Fischer *et al.* (2005) estimated adaptation costs through meeting future irrigation demands by 2080 to be US $24 - 27 billion per year for an unmitigated scenario and US$8 - 10 billion per year less for the mitigated B1 scenario.

3.2.2 Global estimates

While useful for budgeting specific projects, studies costing single adaptation options do not answer the questions necessary for discussions about international financing needs, which require estimates of the total costs of adaptation. A number of studies have therefore attempted to cost adaptation to climate change at the global level, as seen in Table 8, below. Until recently these have all essentially calculated a percentage 'mark-up' to the cost of investment flows, which is deemed necessary to 'climate-proof' them – referred to as an investment and financial flows (IFF) approach.

Table 8: Global estimates of costs of adaptation (Source: adapted from Parry *et al.* 2009).

	Cost (US$ billion per year)	Methodology
World Bank (2006)	9 – 41	Estimated the fraction of current investment flows that is climate sensitive, and then used a 'mark-up' factor to reflect the cost of 'climate-proofing' these. They assumed that 2-10% of gross domestic investment (GDI), 10% of foreign domestic investment (FDI), and 40% of official development assistance (ODA) was climate sensitive, and that the mark-up to climate-proof them was 10-20%.
Stern (2006)	4 – 37	Used the World Bank's methodology, but reduced the mark-up to 5-20% and the share of climate-sensitive ODA to 20%.
Oxfam (2007)	> 50	Added additional cost items to the World Bank's figures, including the cost of community-level NGO work (extrapolated from 3 projects), and of financing NAPA-style programmes (based on 13 NAPAs).
UNDP (2007)	86 – 109	Adopted the Stern (2006) assumptions, except used a 17-33% share for climate-sensitive ODA, and included costs of adapting poverty reduction strategies ($44bn pa) and strengthening disaster response systems ($2bn pa).
UNFCCC (2007)	49 – 171 (28 – 67 in developing countries)	Commissioned five sector studies (including agriculture, forestry and fisheries) and estimated the costs for the year 2030.

These figures have proved valuable in focusing attention on adaptation, and in highlighting the need for financial support for developing countries to adapt. However, the wide discrepancies between the figures – which vary from US$4 to over US$100 billion per year, even between studies that used very similar methodologies and assumptions – call into question their validity. It is clear that small changes in the parameters, which are themselves far from certain and based on little empirical information, have an extremely large influence on the total costs calculated. Importantly, they pay little attention to what specific adaptation measures might be, meaning they remain of limited use to decision makers attempting to evaluate alternative adaptation options.

The UNFCCC (2007) study used an approach that varied slightly from the other studies. It calculated the total costs of five separate sector studies, covering agriculture, forestry and fisheries, water supply, human health, coastal zones and infrastructure, and derived the total cost of adapting to climate change at between US$49 and $171 billion for the year 2030. This includes US$11.3 - $12.6 billion to adapt agriculture, forestry and fisheries (US$7 billion of which will be needed in developing countries due to additional costs required for research, extension and physical capital expenditure) (McCarl 2007) – the first global estimate of the costs of adapting the agricultural sector to climate change. In a recent and widely-cited critique of the UNFCCC approach, Parry *et al.* (2009) argue that the current figures are likely to be substantial under-estimates, by a factor of 2-3. In particular, the UNFCCC study only includes certain sectors, and only partially covers some of the sectors it does include. They argue that although the McCarl study, which provided the estimates for the agriculture and forestry and fisheries sectors to the UNFCCC study, is a reasonable first estimation, its top-down approach means it is very difficult to verify its conclusions, and that the costs are likely to increase as we get more details about on-the-ground costs. This highlights a general challenge in bridging the gap between global top-down studies and location-specific studies looking at the costs of adapting to climate change.

Parry *et al.* (2009) highlight a number of issues which must be considered for future estimates including: the scarcity of information about the scale of likely future impacts and the costs of avoiding them through adaptation; a lack of case studies to test the top-down approach; that the idea of using a 'climate mark-up' may only be appropriate where current levels of investment are adequate; determining how much of the climate impact should be adapted to and how much should be left as residual damage; the need to consider soft adaptation as well as infrastructure development; and questions about how adaptation costs will vary over time.

3.2.3 Beyond IFF

The significant uncertainties surrounding the results of global IFF studies mean there is a need for country-level case studies to validate the global findings, as well as analyses that cost specific adaptation measures to inform the policy process. A number of authors and projects have recognised this research gap and are currently focusing on this area, signalling a step away from the global IFF costing methodologies and towards sector- and location-specific studies.

Some of the earliest available sources of country-level costings of specific adaptation measures are the **national adaptation programmes of action (NAPAs)**, developed by Least Developed Countries (LDCs) following discussions at COP7 of the UNFCCC about the need to enhance adaptive capacity to climate variability in LDCs. NAPAs provide a process for LDCs to identify and prioritise adaptation actions that will address their urgent and immediate adaptation needs, by collating existing knowledge and through participatory workshops. By submitting its NAPA to the UNFCCC Secretariat, a country becomes eligible for funding from the LDC Fund, managed by the Global Environment Facility (GEF), to implement the programme. As of March 2010, 44 countries had submitted NAPAs, each specifying between two (Afghanistan) and 28 (Mauritania) NAPA projects each.

As the NAPAs contain budgets for each of the projects, these can provide a useful indication of the scale of adaptation costs across the 44 countries involved. For example the 15 projects proposed by Bangladesh total $74.8 million over the project lifetimes, including three agricultural projects totalling $18.15 million, and the five projects proposed by Malawi total $22.93 million, including one agricultural project costing $3 million. The total of all the agriculture and livestock sector projects across the 44 countries comes to $138 million.[1] The total cost of the NAPA project is about $2 billion, while the total cost of agricultural projects in these NAPAs is about $118.4 million, ranging from $16,700 for the least cost project in Nepal to $18.15 for the costliest project in Bangladesh. These estimates are based on the UNFCCC NAPA database as of 17 September 2011 (http://unfccc.int/cooperation_support/least_developed_countries_portal/napa_priorities_database/items/4583.php).

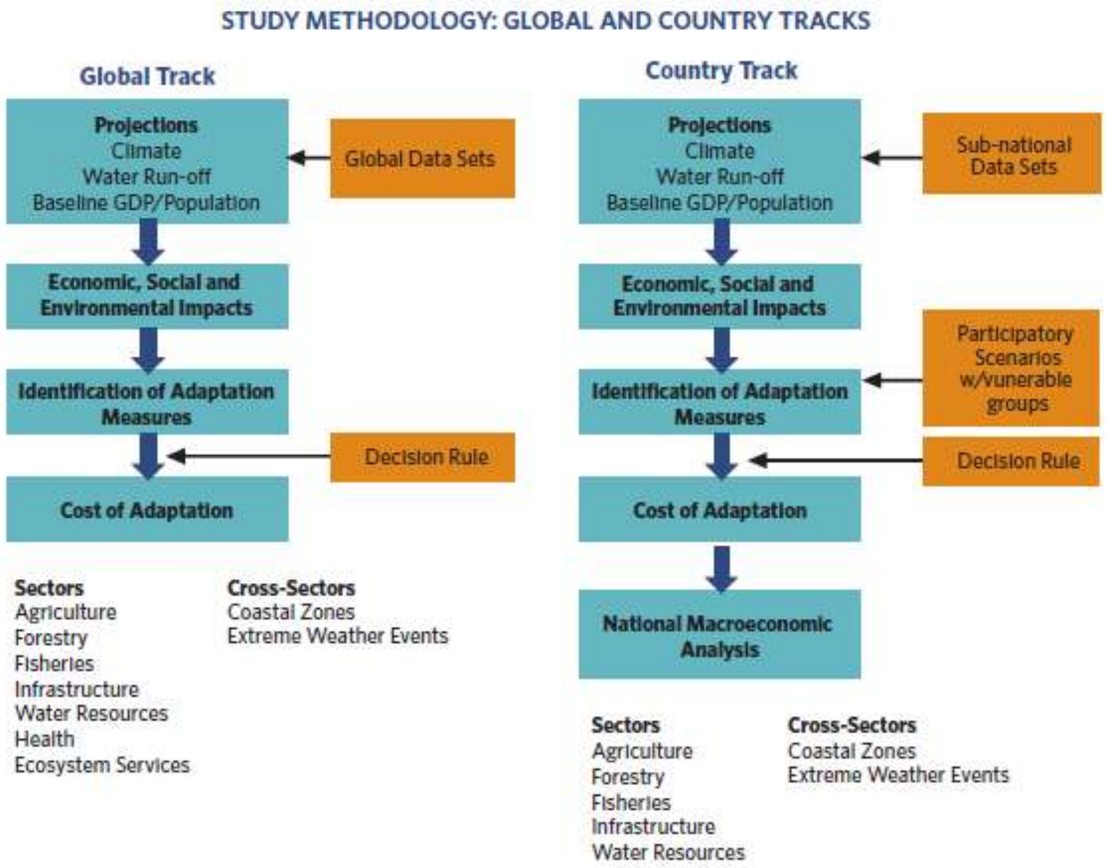
NAPAs have played an important role in providing the costs of specific examples of the types of adaptation actions that the countries are likely to undertake. However, the figures are not comprehensive in that they only cover the adaptation required to respond to the countries' most pressing needs, and they are therefore unable to verify the global IFF estimates by themselves.

The World Bank's Economics of Adaptation to Climate Change project (World Bank 2010) aimed to address the knowledge gap that exists between the global IFF estimates and information available from NAPAs by using a twin-track approach that looked at adaptation costs at both national and global levels. Both the global track and the country track used a methodology that involved projecting what the world will look like between now and 2050, with and without climate change. The project then used the differences between the two to

[1] Excluding Niger, which does not give a budget for its proposed projects.

predict climate change impacts on economic activities, people's behaviour, environmental conditions, and physical capital, and identified adaptation measures that could address these impacts. Finally, it costed these adaptation measures. The country track additionally placed these costs in context by using them as part of a national macroeconomic analysis.

Figure 2: Methodology of World Bank study (Source: World Bank 2010a).



The global track, like the UNFCCC study, estimated separately and then summed the adaptation costs for the major economic sectors; however, unlike the UNFCCC study, it specified the adaptation measures which it costed – a considerable methodological step forward. Estimates of the total cost between 2010 and 2050 of adapting to an approximately 2°C warmer world are in the range of US$75 - $100 billion per year (World Bank 2010a).

Nevertheless, questions regarding the assumptions underlying the individual sector studies that made up the cross-sectoral cost estimate highlight the continuing challenges of assessing the costs of adapting to climate change at this level. The World Bank's methodology and conclusions about the agricultural sector are based on that of the **International Food Policy Research Institute** (IFPRI) (Nelson *et al.* 2009). This study models crop growth for five main crops using the DSSAT model in the climate of 2000 and then under two 2050 climate change scenarios by considering the effect of water availability for irrigation on crops, and running the model both with and without CO_2 fertilisation effects. It then uses the supply and demand IMPACT model to model food prices and the subsequent impact on calorie consumption and the number of malnourished children as a measure of welfare. Calorie availability in 2050 is estimated to be lower than the 2000 levels throughout the developing world, and child malnutrition is estimated to increase by 20 per cent compared to a world with no climate change by 2050. South Asia and sub-Saharan Africa see the most pronounced negative effects, while East Asia and the Pacific have mixed results.

The study considers the costs of returning the per capita calorie consumption and child malnutrition numbers to the values they are projected to be in 2050 in a world without climate change. It concludes that the costs of achieving this by investing in agricultural research, rural roads and irrigation are between US$7.1 - 7.3 billion.

However, in reality it is likely that a country would choose to accept some of the residual damages and undertake only the adaptation measures that are cost-effective, rather than aiming to return calorie consumption and child malnutrition to the levels they would have been without climate change. In addition, although investing in agricultural research, rural roads and irrigation is likely to be an effective adaptation action, other measures – in particular the various forms of both soft and autonomous adaptation – will also play a role. These two points mean the IFPRI study does not address the questions most relevant to decision makers about the costs of adapting agriculture. In addition, more practical considerations – such as the importance of, and difficulty in, choosing the 'correct' development baseline – mean it is difficult to get the best answers to the questions it does ask. Nevertheless, it is an interesting approach and the figures derived a fair approximation, at the upper end of the UNFCCC estimates.

The country track of the World Bank study varied from the global track by using a macroeconomic modelling framework to derive information required for national-level decision making and by using a bottom-up participatory scenario development (PSD) method to identify specific adaptation pathways. The PSD proved a valuable addition to the project as it highlighted how vulnerability is socially differentiated, and was able to take account of autonomous forms of adaptation.

The country track methodology was used in seven countries: Mozambique, Ethiopia, Ghana, Bangladesh, Bolivia, Vietnam and Samoa, looking at between three and five sectors and choosing an appropriate macro-economic model for each country. Because of the importance of the sector, only the country studies in Bangladesh and Samoa did not include agriculture.

Table 9: World Bank country case studies.

Country	Sectors considered	Agricultural adaptation options and their costs
Mozambique	Agriculture, Water, Roads, Hydropower, Coastal, Extreme Events, Social	Adaptation measures include sealing unpaved roads, investing in research and development, and investing in primary education. Expanding irrigation was also considered. Investment costs are likely to be about US$400 million per year over 40 years.
Ethiopia	Agriculture, Water, Roads, Hydropower, Extreme Events, Social	A portfolio adaptation strategy including investments in research and development, and irrigation and drainage, would have an average annual cost of about $70 million for the agricultural sector.
Ghana	Agriculture, Water, Roads, Hydropower, Coastal, Extreme Events, Social	High priorities included: increased investment in agricultural R&D, backed by extension services, to adapt crop varieties; improvement in water storage capacity; and provision of rural roads. Restoring total welfare to the baseline, rather than restoring each sector to the baseline, would have an economy-wide cost in the range of $236 - $764 million per annum.
Bolivia	Agriculture, Water, Social	Used a qualitative matrix to categorise the economic, social and environmental costs of a range of options in the agricultural sector, including irrigation, changes in crop varieties and sowing dates, use of insurance and agricultural subsidies, climate forecasts and early warning systems, market access, and research and extension. The estimated cost of the additional water storage required to match future monthly water deficits due to climate change would add $12 million to the projected baseline (no climate change) of irrigation needs by 2050 under the wet climate scenario, and add $60 million under the dry climate scenario.
Vietnam	Agriculture, Water, Coastal, Social	Autonomous adaptation will include changing sowing dates, changing crops, reinvigorating local varieties, introducing salinity-tolerant rice, finding new water sources, and introducing fish-rice rotations. Planned adaptation will include increasing spending on research, development and extension, and expanding irrigation. For the period 2010 - 49, average annual spending on agricultural research, development, and extension activities is assumed to increase by about 45 per cent to achieve a 13.5 per cent increase in crop yields by 2050, equivalent to a total cost of $1.5 billion at 2009 prices. Similarly, the total cost of additional investment in irrigation expansion is estimated as $4.8 billion at 2009 prices. Hence, the total cost of implementing these two adaptation options is estimated to be $6.3 billion at 2009 prices.

These country studies present a greater degree of detail than previously seen, but also serve to highlight the considerable challenges of costing agricultural adaptation at the national level. In particular, the country teams had varying degrees of success in ascribing costs to the selected adaptation options with each making different assumptions and including different aspects of adaptation in the costing, making it difficult to directly compare the results from the different countries. It is clear that some types of adaptation options are easier to cost than others. For example the teams were successful in costing investments in hard infrastructure options (such as water storage or irrigation) but few placed quantitative values on soft adaptation options, following a decision to select hard measures over soft measures because they were easier to quantify.

Although the study has brought national and global level costs closer together, the team was only able to make limited comparisons between the country and the global analyses, and the results from each are presented in separate sections. This signifies the continuing difficulties in linking costs across different levels.

Others working to address the complex realities of costing adaptation include the **Economics of Climate Change Adaptation Working Group**, which is a partnership between McKinsey, GEF and others. They have developed a framework for decision makers to understand the impact of climate on their economies and identify actions to minimise impact at least cost (McKinsey 2009). Their methodology includes quantifying a location's 'total climate risk' by considering existing climate risks and the extent to which future economic growth will put additional value at risk, and then using a cost-benefit analysis (CBA) to assess specific adaptation measures, including those relating to infrastructure, technology, behaviour and finance. The CBA involved a bottom-up approach to costing (including inputs such as hourly wages) and calculating the loss averted by running a loss model with and without the adaptation measure under consideration.

The Working Group tested the methodology over eight case study regions, focusing on adaptation to specific climate change-related risks, four of which were agricultural. These included north and northeast China (drought risk to agriculture); Maharashtra, India (drought risk to agriculture); Mopti Region, Mali (risk to agriculture from climate zone shift); Georgetown, Guyana (risk from flash floods); Hull, UK (risk from multiple hazards); south Florida, USA (risk from hurricanes); Samoa (risks caused by sea level rise); and Tanzania (health and power risks caused by drought).

They conclude that climate change risks between 1 - 12 per cent of national GDP by 2030 in these regions, with low-income populations most at risk. They showed, however, that 40 - 68 per cent of this loss could be averted through cost-effective adaptation measures, which are often beneficial for economic development regardless of climate change.

Important methodological conclusions are that it is possible to apply a common framework across very diverse situations and that the need for adaptation, and the best approach, vary significantly between different localities, suggesting that it is multiple local assessments that are required, rather than simply extrapolating a small number to the national (or international) level. This approach addresses the need for information to be relevant to decision making by focusing on the local (and potentially national) level and by the fact that it considers specific adaptation measures. It is limited in scope, however, by its use of discrete scenarios based on assumptions about climate change and economic and population growth, by only considering specific hazards and, perhaps crucially, by the fact that it focuses on physical assets at the expense of other social and environmental impacts that may play a large part in people's livelihoods.

The **AdaptCost Africa** project**,** funded by UNEP under the Climate Change-Norway Partnership, combines different lines of evidence to produce a range of estimates for the financial needs for climate change adaptation in Africa. The project emphasises that different approaches are required to answer different policy questions at different scales, and assesses four key lines of analysis: integrated assessment models, estimates from investment and financial flows assessments, national to sectoral studies, and a process-based approach based on adaptation signatures. It proposes benchmark figures of US$25 billion per year by 2012, and a central benchmark of US$30 billion or an upper benchmark of $60 billion per year by 2030, but is keen to emphasise that the estimates depend on what exactly is included – for example whether the costs include social protection.

Researchers involved in the **Assessments of Impacts and Adaptations to Climate Change** (AIACC) initiative, which aims to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries, have published a large number of papers and reports on a range of topics. These include a study that carried out detailed cost-benefit analyses of crop fertilisation and irrigation as strategies to adapt to climate change in the Gambia, showing each approach to be equally effective (Njie *et al.* 2006). This study highlights an important issue about the distribution of costs; although the CBA show considerable benefits at a macro-economic level, farming households do not see an increased income that matches their increased costs.

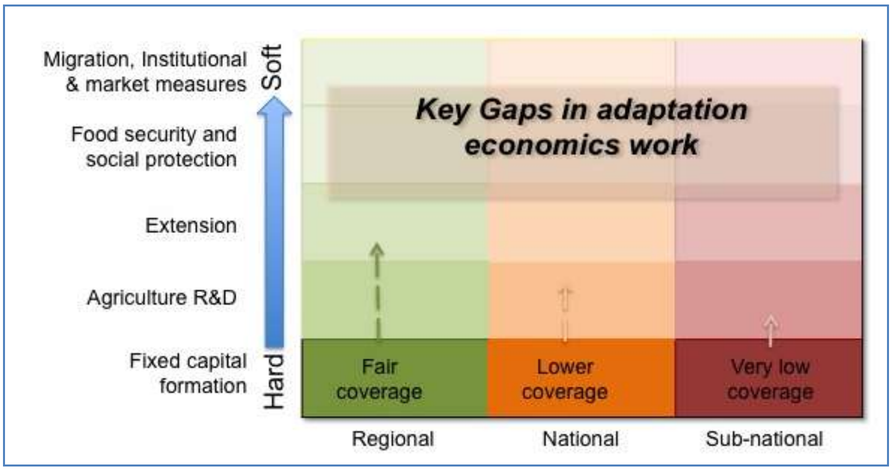
3.3 Discussion and conclusion

Costing adaptation to climate change has risen in prominence in the political agenda in recent years and a large number of governments, donors and other organisations are currently working on the issue. However, for now, the literature assessing the costs of adapting to climate change – both in general and in the agricultural sector specifically – remains constrained in a number of ways, meaning it is of limited use to policymakers on the ground.

It is only in the past few years that various studies - such as the World Bank's - have begun to research on-the-ground case studies and there remains a need for a wider spread of examples at this level, investigated using differing methodologies, to provide empirical evidence to support the top-down approaches. Climate change will be felt, and must be addressed, at the local level – meaning decision makers need more information about strategies to adapt at this level that link to national and international policy needs. In addition, there is a need for information about climate change adaptation to be sector-specific in order to allow it to be mainstreamed with sector policies and plans. This separation is currently reflected in the policy environment, with countries often addressing adaptation through policies such as NAPAs, and agriculture (and other sectors) through SWAPs, poverty reduction strategy papers (PRSPs), etc.

Despite a general acceptance that adaptation must comprise both hard and soft measures, costing studies have generally focused on developing infrastructure, in part because these measures are simply easier to cost. Figure 3, below, highlights a bias in the costing literature towards both regional level analysis and a focus on hard adaptation measures.

Figure 3: Key gaps in adaptation economics work (Source: Dyszynski 2010).



The limited number and types of adaptation strategies investigated has implications for both the cost estimates and, perhaps even more importantly, for the signals this sends to policymakers about what is needed. This is exacerbated by the fact the existing literature examines the costs of adaptation on its own, overlooking the inter-relationship between adaptation and mitigation, highlighted as important by a number of authors (Ayres and Huq 2009; Agrawala *et al.* 2010), and often attempting to separate 'pure' adaptation measures from those considered part of 'development'.

Many of the available studies fail adequately to address the *process* of adaptation and the political realities surrounding it; they often cost adaptation with a static approach that compares a 'before climate change' situation with an 'after climate change' one, ignoring the costs of making the change. While such approaches establish certain important costs they miss others (e.g., in the case of migration when a population could have an equally high level of welfare in a new location once it had established itself, but is likely to encounter substantial reductions in welfare while relocating). As such it is useful to split the costs of climate change into transition (or adjustment) costs and equilibrium costs (Tol *et al,* 1998). This is linked to a broader point that most of the estimates currently available are presented as static costs per annum, overlooking significant variations between years. Estimates that highlight the dynamic nature of adaptation costs would be of more practical use to decision makers.

As well as the need to consider how costs vary over time, there is also a need to consider the distribution of costs between different actors. While the market might solve the climate problem through adaptation, the distribution of the market benefits may change substantially. For example, if prices rise as a result of the adaptation, producers may benefit at the expense of consumers. Moreover, the distribution of the benefits among producers may be geographically uneven with, for example, developed country farmers benefiting at the expense of those in developing countries. Despite the importance of this, costing studies have so far struggled to incorporate it.

Estimates about the costs of adaptation to climate change are inherently uncertain because they encompass uncertain climatic projections and uncertain socioeconomic projections under an uncertain policy environment. The current literature addresses this by basing the cost estimates on more than one scenario – a possible future, rather than a prediction *per se*. Although this allows a likely range of values to be calculated, it fails to address the probability distributions of both the climatic and socioeconomic projections. In particular, the scenarios used to represent climate change are often overly simplistic, for example considering the physical impacts of climate change to be linear when it is generally accepted that it is extreme events that will have the greatest impact on society. This may considerably influence the cost estimates.

This discussion has highlighted the considerable challenges of devising quantitative estimates of the costs of adapting agriculture to climate change that are meaningful to decision makers on the ground. The limitations of a selection of studies underline a range of future research needs, including the need to:

- Incorporate the complex and often indirect ways in which climate change impacts on agriculture.
- Provide on-the-ground case studies to verify early global-level costing estimates.
- Present sector-specific costs.
- Include both soft adaptation measures and hard adaptation measures.
- Consider the synergies between adaptation and development.
- Include transition costs, and present how costs vary over time.
- Highlight the distribution of costs between different actors.
- Address issues of uncertainty in climatic and socioeconomic projections.

The analytical framework developed for this study and presented in Section 4 attempts to address these.

4. Analytical framework

Planning and costing adaptation are inseparable, at least when designing policies leading to action. Costs are derived from a well-specified planning framework, while plans themselves are only useful if they can be implemented within a certain budget constraint, because the actions come at a cost. The inadequacies of existing approaches for costing and planning adaptation in developing countries motivate the development of a framework that recognizes the nature of developing country adaptation within a development context. This framework should also be usable by researchers and planners in these countries.

Climate adaptation is a contested issue. Understanding the issue as a 'wicked problem' (Rayner 2006; Mathur 2011) reinforces general insights that are well documented in various communities of practice on climate change vulnerability, impacts and adaptation (e.g., Downing *et al.* 2006). Distinctive features of wicked problems (Rittel and Webber 1973; Levin *et al.* 2007), and their corresponding interpretation for climate adaptation, are:

- Stakeholders have radically different world views and different frames for understanding the problem. Climate adaptation is approached as everything from 'good development' to just the additional risk of climate change impacts.
- No central authority. No one stakeholder can impose their framing of the problem, despite recourse to the UNFCCC, IPCC and 'authorities'.
- The solution depends on how the problem is framed. Anticipating future climate change impacts implies a very different set of solutions than reducing present climate risks; both are only indirectly linked to social protection and infrastructure that might be termed 'development'.
- Time is running out. The window for adapting (or more generally achieving resilience) is the next few decades at best.
- The problem is never solved definitively. The race against changing risks and surprise means the outcomes of adaptation are only anticipated benefits, and climate impacts will continue for a century or more (although hopefully substantially abated as mitigation policy stabilises global emissions).
- Hyperbolic discounting occurs: the long-term future is valued more than expected. Various concerns over climate change, for instance common but differentiated responsibility, explicitly require that long-term prospects are part of current decision making. Indeed, climate change is the benchmark environmental issue for using low social discount rates (as argued in the *Stern Review*).

These complexities are compounded by the reality that effective adaptation will involve the planned and autonomous decisions and actions of actors operating at different levels, and influenced by external factors such as information, policies, finance, etc. Similarly, adaptation operates inseparably within the context of existing development and livelihood strategies being pursued by governments, households, private businesses and donors.

As a wicked problem, there are implications for the economics of adaptation. The most important is that different actors come to the issue with their own decision frameworks. There is no single approach to the economics of adaptation that spans the entire range of interpretations. With very little adaptation experience on the ground, for sufficiently long enough periods to draw conclusions about costs and benefits, the use of econometric approaches is very limited. We are also uncertain about future climates and how future generations will adapt to them within their own development contexts. This calls for multiple lines of evidence, recognizing the importance of stakeholder-driven frameworks.

This project has developed an overall framework based on the principle of adaptation as a pathway, grounded in local case studies and reflecting global agricultural systems. The framework provides an understanding of the *process* of agricultural adaptation that is more realistic than the predict-and-provide approach that takes adaptation as a reaction in a scenario of future climate change impacts. It is imperative that this conceptual framework is grounded in empirical studies: the pathways are idealised representations that only partly reflect the local realities of resources, institutions and decision making. Section 4 provides more detail on:

1. Adaptation signatures as idealised pathways of adapting well.
2. Locating case studies in global agricultural systems, envelopes of climate change and typical adaptation pathways.
3. Understanding climate envelopes.
4. Procedures used in developing the case studies.

4.1 Adaptation signatures: pathways of adapting well

We use the term 'adaptation signature' to refer to a stylised pathway of adaptation (Watkiss *et al.* 2009; Downing 2011). The starting point is two key principles:

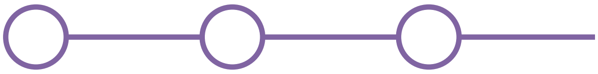
- Adaptation is a socio-institutional process, with social learning a key aspect of 'adapting well'. It thus has a temporal dimension to it.
- Stakeholders come to adaptation with their own decision frameworks and these are the boundary conditions of their adaptation strategies.

These principles can be operationalised and depicted as a simple metaphor whereby adaptation is a journey: decision makers follow various pathways to navigate across the adaptation landscape. Of course, there are many such paths, all local in some respect but sharing common features as well.

The adaptation pathway can be viewed as a sequence of decision nodes (Figure 4). Decision making at each node is bounded, by the stakeholder framing – including the choice of criteria, consideration for future conditions and decision nodes. Each node consists of a combination of decisions and actions undertaken by several actors and influenced by several external factors. In the case of adaptation pathways, several types of future nodes are worth noting:

- Social learning would continue, even though future nodes look much like the present. This is implied in the figure below.
- Current decisions might be designed to significantly expand the decision space for future decisions. This might involve gathering new kinds of information, entraining new actors, or changing decision criteria; all are substantial changes to the adaptation space. Mandatory reporting requirements are a topical example in the UK.
- More (potentially desirable) options might be available in the future, but only if certain decisions are taken in previous nodes. For instance, weather insurance requires a dense network of weather stations and at least 10 years of data to establish the baseline risk.
- Pathways may 'lock-in' some choices, or lead to 'dead ends'. Without knowing whether these are justified by present costs and benefits, many adaptation plans assume that flexibility is a key attribute of climate resilience. For instance, major reservoirs are a long-term commitment that precludes other adaptive options.

Figure 4: Adaptation pathways as a sequence of decision nodes (Source: Downing 2011).



Understanding adaptation as a process highlights several aspects of economic assessment. The standard model is to use some sort of multi-criteria assessment (or more formal cost-benefit analysis) using criteria designed for the current decision environment. It is possible to add factors that relate to future impacts (e.g., the benefits of avoiding future climate impacts) and institutional change (e.g., a criterion regarding the sustainability of operating expenditures). However, the signature approach seeks to take on more substantive analysis of pathways:

- What is the value of increasing the range of future choices? Option values might encourage win-win and low regret options for instance.
- What are the 'worst case' costs for strategies that fail due to lock-in or path dependence?
- How robust are strategies against the wide range of plausible futures? Measures of risk aversion might start to capture this concern.
- What is the value of adverse impacts of the adaptation strategy on the future vulnerability of some socioeconomic groups? For instance, increasing flood defenses in one area also increases downstream risks in areas that are not equally protected.
- What is the optimal timing for making a decision? For instance, protecting agriculture from future impacts might be far easier some years into the future if new technology becomes widely available.

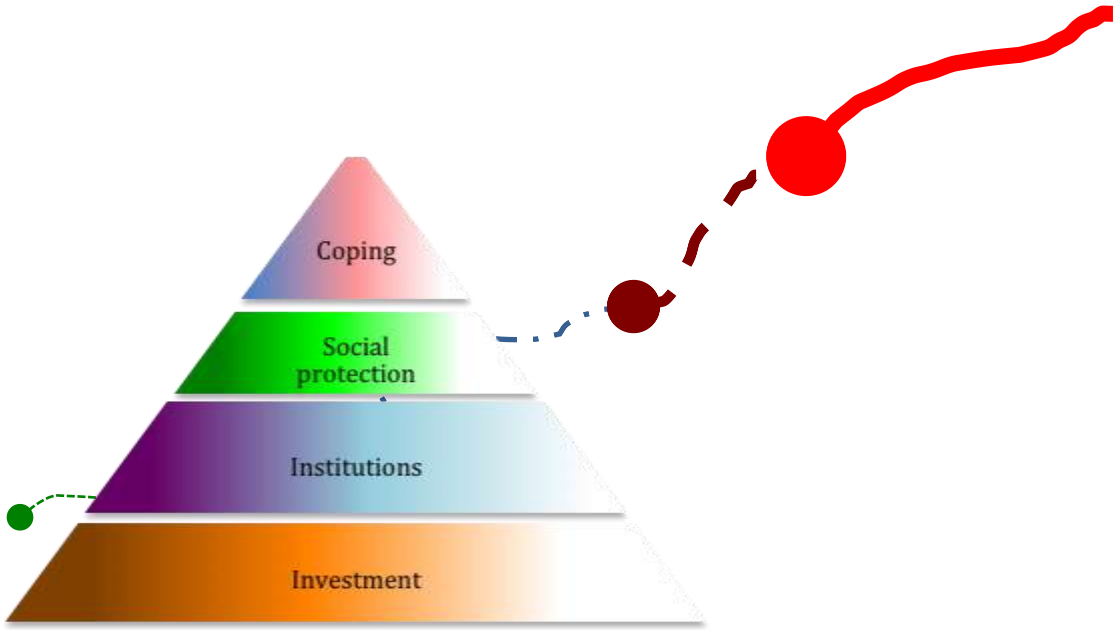
So far, such concerns are not captured in the economics of climate adaptation. Most studies assume that a decision is made in the present only and is removed from consideration of pathways (the McKinsey 2009 model of marginal adaptation cost curves makes this problematic assumption). On the other hand, narrative scenarios represent some of the pathway logic, but rarely are captured in economic assessments (other than a reference case for looking at marginal values).The range of factors to consider in evaluating decisions is suggested in Figure 5 below.

- Investment decisions are generally part of the enabling conditions of development. For instance, a major investment in a reservoir must bring strong benefits from current conditions.
- Institutional developments similarly are mostly driven by current factors, but with a clear mandate to begin preparing capacity for future needs (scaling up).
- Social protection is often given weight in adaptation decision making, particularly where vulnerability is borne by particular groups, or if adaptation actions disadvantage some people.
- Coping with current climate episodes and risks is a mainstream strategy. However, to be effective it must build upon the structural investments, institutional capacity and social protection that are the underlying features of current vulnerability.

Going beyond the 'present' requires:

- Preparing for coming climate change impacts as they stretch beyond the current range of risks and coping ranges (but also being positioned to take advantage of new opportunities).

Figure 5: Aspects of decision making in an adaptation pathway (Source: Downing 2011; see also Watkiss *et al.* 2010).



The future is unknown. This simple statement leads to a clear mandate: uncertainty is the reason for action. The mix of climate resources and risks, socioeconomic exposure, vulnerability, and adaptive capacity, say for the year 2030, is not something we can plan for given present understanding. Planning adaptation now includes developing pathways that enable options in the future that are not available at present. Such options may well take 20 years to progress from initial concept to pilot actions and demonstrated capacity for sectoral and national implementation.

Systematic planning for adaptation is desirable. Much of what is learned through pilot actions will be essential to achieve climate resilience throughout a sector. Features of systemic and systematic planning include working at a variety of scales – vulnerability and adaptation are multi-scale, dynamic capacities. Integration across scales, pilot testing and scaling out, building capacity and efficiency that lower the unit costs of adaptation, are all part of a systemic, path-dependent approach. Conversely, lack of systemic understanding may lead to increased costs and even competition between various adaptation plans.

The notion of pathways in the adaptation landscape suggests four levels (see Figure 5). While highly idealised, these levels are indicative of different framings and a progression as climate change impacts become more clearly visible.

- All present decisions are deeply rooted in the current state of development (whether in developing countries or advanced economies).
- The first transition is well underway: motivated by the sense that climate is changing ('time is running out' in the framing as a wicked problem), reducing current structural vulnerability and building risk management capacity are priorities. This is largely the domain of disaster risk reduction (DRR), with effective action depending on existing capacities.

- Early transformations of institutions and planning to prepare for climates of the future are incipient. Learning for existing DRR is a good start with strong co-benefits. But much more is required.
- Effective adaptation to the future is not guaranteed in the present actions and with our present understanding. However, a pathway of adapting well should give people confidence that those risks and challenges can be managed as capacity is developed.

These foundations for understanding adaptation economics inform many elements of this project. For the most part, the project teams have evaluated adaptation measures as opposed to broad strategies and immediate decision framings (generally limited to disaster risk reduction and local economic criteria). Scaling up to the national level remains a difficult undertaking.

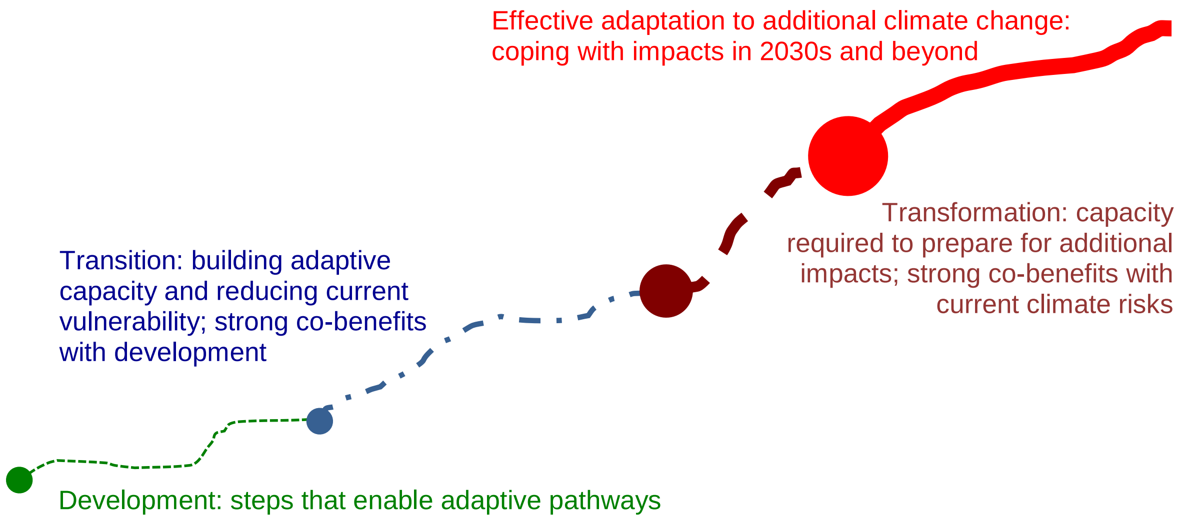
The notion of adaptive pathways provides a means of synthesis for each country study. Moving beyond the indicative signatures to the global scale is not possible at this time. However, the pathway approach provides a robust means for a comprehensive assessment in the future. We believe it is a far more useful framework than relying on model predictions.

A particularly intriguing issue is: *what are the key features for agriculture that we want to have in an adaptation pathway by 2030*? Usually we construct climate impacts and adaptation against a 'business as usual' reference case. In contrast, an assessment of the features of an attractive vision of 'adapting well' might motivate innovative solutions.

> The costing and planning of adaptation are inherently linked processes. The 'adaptation pathways' approach is useful in both conceptualising the complexities of adaptation, and in the practical planning of agricultural adaptation – in particular allowing the distribution of costs to different actors over time to be investigated.

While a functional toolkit and emerging practice are gaining ground, adaptation signatures are still illustrative of the sort of practicable adaptation decision science that will be necessary in the future. An early conclusion, however, is that a global selection of strategies and measures is not possible (in terms of CBA or optimal choice as a top-down process), although there are many common features that can guide 'good enough' practice that is fit for purpose, and opens up new alternatives. Participatory and institutional economics are likely to constitute significant guide posts for the present needs, far beyond the range of micro-economic decision tools that are constrained to rather narrow selection of choices.

Figure 6: A progression of objectives in adaptation pathways (Source: Downing 2011).



4.2 Locating case studies

This approach to adaptation – as pathways of decision nodes – allowed the project to investigate the roles different actors at different levels play in adapting agriculture to climate change. By considering the process of adaptation at this level of detail, the project is able to ascribe costs of agricultural adaptation differentiated by actor over time. This is relevant to both country-level decision makers, who must chose how best to support agricultural adaptation, and to global policymakers, providing bottom-up costings to verify global estimates and providing information as to where and how international adaptation finance should be spent.

To do this, the project carried out five in-depth case studies. Each case study represents an instance of an agricultural system, defined as 'a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate' (Dixon *et al.* 2001). The focus on agricultural systems allowed a consideration of the many different roles and functions performed by agriculture, as well as a recognition that even within a country, agriculture is highly heterogeneous – crucial in representing accurately the decisions that different actors face. Of course, each case study is not a complete representation of the selected agricultural system. Table 10, below, sets out the case studies.

A 'systems approach' incorporates the heterogeneous and multifunctional nature of agriculture.

Table 10: Case study farming systems.

Country	System description	Primary goal	Defining feature	Associated crops	Most closely-related FAO farming system
Tanzania	Pastoralism livestock systems	Store of wealth	Extensive livestock management based on mobility and minimum external input use	Maize, *lablab* (type of bean), cowpeas, sorghum, millet	Pastoral
Nepal	Integrated maize-based farming systems in the mid-hills	Food sufficiency	Integrated farming with mixed cropping	Maize, rice, wheat, legumes, millet, livestock, vegetables, fruit trees	Highland mixed
Malawi	Subsistence rainfed food production	Food security	Smallholder maize production	Tobacco (for cash), cassava, sweet potato, beans and some livestock	Maize mixed
Rwanda	Smallholder cash cropping	Cash	Perennial crops dominated by coffee	Banana, Irish potato, maize, beans, livestock/cattle	Perennial crop
Bangladesh	Deltaic, flood-prone cropping systems	Food and livelihood security	Saline-prone rice production in lowland areas at small and medium scales	Fisheries and aquaculture, livestock, vegetables, pulses, potatoes, maize, wheat	Rice

The case study systems were chosen on the basis of their vulnerability to climate change, their importance to national agriculture and poverty reduction, and their representativeness of agriculture both within the case study countries and across the developing world.

Teams based in each of the five countries: Bangladesh, Malawi, Nepal, Rwanda and Tanzania, undertook the case study research. Although each of the teams followed a similar procedure – considering in detail how climate and climate change affect agriculture; how households and communities currently cope with climate variability and how they may do so under a future changing climate; the roles of different stakeholders at different levels in supporting agricultural adaptation; and the costs each of these stakeholders are likely to bear in adapting to climate change – the detailed research activities varied depending on the specific local circumstances.

The project did not attempt a full typology of adaptation signatures as the intersection of actors, agricultural systems and climate vulnerability. The typical matrix of community-based and ecosystems-based adaptation scaled from local (and individual action) to national and sectoral planning is a static view. While descriptive, such a matrix doesn't capture the objectives and planning frameworks of particular stakeholder regimes. Archetypical adaptation signatures include:

- **Early warning and use of climate forecasts**. Seasonal climate outlooks are a common tool in risk management and disaster risk reduction highlights the benefits of early warning systems. The stakeholders include climate forecasters, disaster-emergency managers, and end-users. Enduring benefits of such decisions are likely as farmers continually adjust to each season's conditions. While a common adaptation pathway, none of the case studies focused on this signature as the main priority.
- **Resource management and efficiency**. Most agricultural systems are not optimally tuned to existing climate resources and risks – improving efficiency of resource use would provide greater scope for coping with changing risks in the future. Land-use planning and establishment of grazing reserves is a good example in pastoral systems – the case taken forward in Tanzania. Most of the case studies developed pathways in this category: promoting forms of agricultural technology that increase production, reduce risks of adverse climate extreme events, and increase resilience among vulnerable households.
- **Major infrastructure investment**. Stakeholders who manage major investments such as roads, coastal defenses, water, and markets are key to the larger costs of adaptation. The overlap with development is a recurrent theme. Agricultural adaptation may be most viable through increased market development – including road and rail transport within a country and overseas exports. However, this is an area of considerable debate and none of the case studies chose to evaluate major infrastructure as adaptation options.
- **Research and development**. For most farming systems, technologies are currently available that are the first step in promoting resource efficiencies. However in the next decade or so, more demanding climates are likely to require significant new technology. For instance, saline-resistant crops in Bangladesh are useful at present, and will become more so in the future (one of the project case studies).
- **Awareness, information and knowledge management**. Most adaptation pathways have some elements of building capacity through awareness and knowledge management. However, additional stakeholders are often key to this pathway, for instance at the science-policy interface, in formal and informal training, and for public campaigns. None of the projects developed detailed information campaigns; all worked with stakeholders as part of the project design.

4.3 Understanding climate envelopes

Climate change is uncertain: the pathways framework seeks to make progress in building capacity to act under conditions of uncertainty. The major domains of uncertainty in the future are not climate-linked; the drivers of economic development, equity and poverty, social relations, and governance are far more important for defining who is vulnerable to climate outcomes in the next two decades than is climate itself. However, climate conditions are changing and recognition of the changing resources and risks is a core element of the project.

At the national level, adaptation pathways have been evaluated according to exposure to climate change (see Watkiss *et al.* 2010). Each case study brought into its analysis available information on current climate conditions and prospects for future climate change.

The main sources of climatic information were: meteorological data from stations in or near the study sites; local perceptions of climatic events and trends; and climate projections in the form of 'climate envelopes'.

Local meteorological data were available from both public and private meteorological stations. The nearest meteorological stations were generally found within the local government area, but not the village, of the study site. The local data showed average values and past and current trends of temperature and precipitation, and were used to provide a baseline against which adaptation measures could be considered, as well as to verify the local perceptions.

Local perceptions of climatic trends were obtained through the household surveys and focus group discussions (FGDs). Households were able to give detailed qualitative descriptions of past climate events and trends. This was an extremely useful source of information because its spatial resolution is the unit of decision making (the level of the farm), and because it is directly linked to the climate hazards affecting agriculture.

Both the local meteorological data and the local perceptions of climatic events and trends are, however, unable to provide projections of likely future climates. For this, **climate envelopes** – containing a range of climatic parameters including monthly total precipitation, monthly dry spell duration, monthly mean maximum daily temperature, and monthly mean number of days exceeding 32°C – were prepared using data from local meteorological stations. These were chosen on the basis of their relevance to agriculture and importantly show a range of possible responses, not a predicted value, for each parameter, as seen in the figure below of monthly mean change in days exceeding 32°C in Chikwawa, Malawi, at the spatial resolution of an individual meteorological station.

Figure 7: Example of a climate envelope.

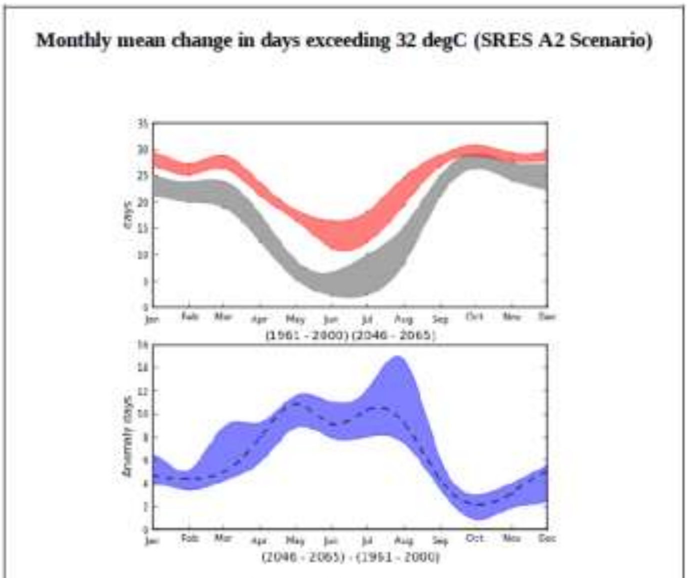


Figure 9: Change in monthly days exceeding 32degC for Chikwawa - Illovo-Alumenda station. Grey envelope represents 10th to 90th percentile range of the control period multi-model climatologies (1961-2000). Red envelope represents the same but for the future period multi-model projections (2046-2065). Anomaly plot envelope represents the 10th to 90th percentile range of anomalies with the median anomaly as a dashed line..

Global climate models (GCMs) are the foundation of climate change projections. These models simulate the global climate system by integrating known physical processes through time. The models simulate the heating effect of the sun, the heat and moisture fluxes from the oceans, the effect of the land surface and vegetation, as well as the effect of greenhouse gases on the atmospheric temperature profile. However, many processes occur at scales that cannot be resolved by the GCM. These processes are approximated through parameterisations. Parameterised processes included cloud radiative effects, convection and precipitation, boundary layer mixing, and many aspects of surface heat and moisture fluxes. Many differences between GCMs are a result of the different approaches to these parameterisations, particularly cloud radiative effects and precipitation processes. Another consequence of importance is that the 'skill' of a GCM to simulate a particular region varies. Each GCM has better skill in some areas than others.

The temptation is to pick the GCM that best represents the present climate of the region of interest. However this is not a valid approach because when generating climate change projections we are looking for an accurate response to changes in GHG concentrations. A GCM that accurately simulates observed climate does not necessarily accurately respond to changes in GHGs. Of course we do not know what an accurate response should be so we have to assume that all models represent an equally plausible response. This is the basis of the development of climate projection envelopes, which represent the range of responses produced by GCMs (see Stainforth *et al.* 2007a; 2007b).

The scale of GCMs has improved significantly in the last 10 years, with many state-of-the-art GCMs able to simulate climates at a scale of around 100km grids. The Coupled Model Intercomparison Project (CMIP3) archive 1 GCMs are typically of lower resolution than 100km, with resolution ranging between 200km and 400km. However, while the native resolution of a GCM may be 200km, the skill of the model at this resolution is typically low due to the GCM's simplified topography and representation of regional processes. GCM skill is much higher when aggregated up to large scales such 500km to 1000km grids. The problem is that these scales are far too coarse for water and agricultural decisions at the local scale; society and ecosystems typically operate at much finer geographical scales too.

Downscaling is the concept based on the observation that local-scale climate is largely a function of the large-scale climate, modified by some local forcing such as topography. There are two main types of downscaling: dynamical and empirical. **Dynamical downscaling** utilises a higher resolution, limited domain dynamical model that follows the same principles as a GCM but, because of the limited domain, is able to be run at much higher spatial resolutions with moderate computation costs. Dynamical downscaling offers a physically-based regional response to the large-scale forcing. However, dynamical modelling is complicated by similar problems to those of GCMs, namely bias and error.

Empirical downscaling utilises various statistical methods to approximate the regional scale response to the large scale forcing. Various methods have been developed. The method used in this project is called SOMD (Self Organising Map-based Downscaling) developed at the University of Cape Town (see: www.csag.uct.ac.za). The method recognises that the regional response is both stochastic as well as a function of the large-scale synoptics. As such, it generates a statistical distribution of observed responses to past large-scale observed synoptic states. These distributions are then sampled based on the GCM generated synoptics in order to produce a time series of GCM downscaled daily values for the variable in question (typically temperature and rainfall). An advantage of this method is that the relatively unskilled grid-scale GCM precipitation and surface temperature are not used by the downscaling but large-scale circulation (pressure, wind and humidity) fields are used instead, which have more confidence in GCM skill.

The CMIP3 archive GCMs are used in this study. The downscaling methodology requires daily fields, which limited the number of suitable GCMs to a total of nine out of a possible 21. Each GCM has a number of simulations. The first is a simulation of the 20th century climate (represented by the period from 1961 to 2000), forced by observed GHG concentrations. This simulation (without additional climate change) is the GCM's representation of the observed or present climate period. It is important to note that there is no correspondence between real years and the years of the 20th century simulations. This means one can expect no likeness between a particular year in the 20th century simulation and that year in the observational record.

Then follows a number of simulations of future periods and GHG concentration scenarios. For this study, the two future periods of 2046 - 2065 and 2081 - 2100 were selected, and one future scenario of GHG emissions (the IPCC SRES A2, representing high growth in emissions). A total of three GCM simulations, one 20th century period and two future periods, were therefore analysed for each particular GCM. Each GCM simulation was downscaled to the station location and various appropriate climatological summary statistics were produced. These are presented in the form of climate projection envelopes. As mentioned above, projection envelopes capture the range of GCM responses to GHG forcing and represent the level of agreement or disagreement between the GCMs.

The climate envelopes were used together with local observations and climate change perspectives to derive adaptation options through consultations with stakeholders in the case study areas.

4.4 Procedures for case studies

4.4.1 Local level

The case study research included local data collection. All the country teams undertook household questionnaires, with three out of the five teams additionally carrying out local-level focus group discussions. These investigated the intricacies of the relationship between agriculture and climate, ways in which the system currently deals with climate variability, and possible future adaptation actions and strategies. In particular these considered:

- The nature of the farming system.
- How climate hazards currently affect the agricultural system and how this is likely to change under a changing climate.
- The socioeconomic characteristics of the area.
- Local-level perceptions as to the future of the farming system under an uncertain climate.
- The availability and use of climatic information at the local level.
- Possible adaptation measures, including the ways in which the community has adapted to current climate variability and a discussion of required adaptation actions.
- The relationship of the local community with district and national level authorities.
- Constraints and barriers to successful adaptation at the local level.

4.4.2 District level

Each of the teams conducted interviews with district- and national-level government and non-government stakeholders, from both agricultural and climate change institutional frameworks, to inform the ways in which agriculture may adapt to climate change, and how the institutional and policy environment supports climate change adaptation in the agriculture sector. The interviews investigated:

- The significance of agriculture to the country, and the challenges it faces under a changing climate.
- The perceptions of these stakeholders as to the future of agriculture in a changing climate.
- Possible adaptation measures and their likely costs.
- The roles played by the various institutions involved in formulating and implementing policies to support climate change adaptation in agriculture.
- How the different institutions interact with each other, including how climate change is integrated into agricultural frameworks, how agriculture is integrated into climate change frameworks, and whether this is effective and sufficient.
- The ways by which the various institutions reach and interact with local communities.
- Sources, flows and allocations of funding for climate change adaptation in agriculture.
- Current and idealised sources, flows and use of information about climate change and agriculture.

4.4.3 National level

The teams collected and analysed government policies relevant to agricultural adaptation, including those of the institutions responsible for climate change and environment, and those of the institutions responsible for agricultural development. This complemented the stakeholder interviews in informing the policy environment research.

Information gathered in the stakeholder interviews and the document audit allowed the teams to analyse the policy environment surrounding agricultural adaptation, in particular considering:

- The institutions supporting agricultural adaptation and the relationships between them (including those from both climate change/environment and agriculture frameworks).
- The policies governing agricultural adaptation, including current and planned steps to support agricultural adaptation and the priority ascribed to these, the specific objectives of both climate change and agriculture policies as they relate to climate change adaptation, and the extent to which they are complementary.
- The funding for agricultural adaptation, including the amount available from both agriculture and climate change budgets, and the paths by which it flows.

This supported the teams in determining the roles of different institutional actors in adapting to climate change as they developed the adaptation pathways, and highlighted where there is the need for, and capacity to distribute, adaptation finance.

4.4.4 Linking across the levels

The country teams used the results from their local-level research, stakeholder interviews, document audits, and the local climate data, to develop an 'adaptation pathway' for the individual case studies.

The format of the adaptation pathways depended on the nature of the case study, but involved selecting key required actions, and considering where on the adaptation-development continuum these might lie.

The teams then costed the adaptation pathways, providing costs disaggregated by actor over time. The first step was to map specific actions required:

Table 11: Example of a costing template (1).

Action	Actors/level	Now	Later
[Action 1]	Community/local	[list relevant actions]	
	District/meso		
	National		
[Action 2]			
[etc.]			

The second step ascribed costs to those actors that will incur those costs for each of the required actions:

Table 12: Example of a costing template (2).

Action	Actor(s)	Cost	Qualitative factors/notes
[Action A]	(E.g. household, national govt. ministry, research inst., etc.)	[Unit cost]	[list out in bullets]

The data used to cost the actions depended on the nature of the pathway, but varied from current budgets for similar projects to local prices for material and labour.

Although the project did not analyse the benefits of adaptation actions relative to their costs, the teams considered a number of criteria that could be used to prioritise actions, including whether the action is already included in national plans or policies; whether it is a 'no regrets' option; and whether there are other significant environmental or social costs or benefits (including mitigation co-benefits).

Each of the teams held a workshop with national-level stakeholders (including government agencies, donors and NGOs, and technical specialists) following their preliminary results in order to:

1. Communicate the initial findings of the research to relevant stakeholders.
2. Identify the gaps in the study and cover these with the input of key experts in the relevant areas.
3. Initiate discussions on the use of the findings within the country, and the main messages to take to the global synthesis based on the national perspectives.

The workshops included a keynote presentation of research findings and facilitated group discussions with each group attending, and provided the teams with information with which to update their first draft reports.

4.5 Synthesising case study findings

The results from the five case studies were synthesised during a Synthesis Workshop held in Dhaka, Bangladesh during April 2011, and through subsequent analysis of the case study reports. This involved identifying converging and diverging themes, and discussing the implications of topics including:

- The nature of the adaptation pathways.
- The costs of adaptation, and the distribution of these costs.
- The policy environment surrounding adaptation.

In addition, the synthesis included a reflection on the extent to which the procedural framework had been successful in operationalising the conceptual framework, and in particular the use of adaptation pathways as a way of planning adaptation in agricultural systems.

5. Agricultural system case studies: key findings

5.1 Introduction

The methodological framework outlined in Section 4 was implemented in five different countries, with each country covering only one agricultural system. The results from the case studies provide a great deal of evidence and learning, both in terms of the range of adaptation measures and costs of those measures in a specific context, as well as in relation to the process of engaging with stakeholders to develop adaptation costing. Findings include: detailed evidence on the way in which the agricultural system operates; the pathways for adapting to climate change; possible adaptation signatures; key actors at different levels; and the likely costs of implementing the adaptation signatures. While the results are based on a common framework and approach, they demonstrate the heterogeneity that policymakers should expect from adaptation plans from different countries and also the main points that should be taken into account – especially for planning with different actors in the agricultural development, climate change and other sectors.

The study used a bottom-up approach to costing adaptation; as such, adaptation measures and associated costs were identified for specific agricultural systems within specific regions of a country. The important benefit of this approach is that the information presented in the country studies is very much based on local realities, and provides a great deal of context-specific detail. The country teams were able to look at adaptation needs for a particular system in depth, and engage in participatory discussions with local stakeholders. However it also means that the data across countries are not comparable, nor can they be scaled up – the methodologies employed by each country team were tailored to specific circumstances.

Therefore the country studies (which are summarised here) should be read as specific to their context, and provide very useful data for practitioners who are interested in a particular country and/or agricultural system. Wider lessons learned on the process of implementing this methodology are included in Section 7. The detailed findings from extensive surveys and consultations that were followed at local, district and national levels are presented in more detailed country papers. The results are based on several iterations followed by local country teams to incorporate information in different ways, and continuation with these iterations could generate more interesting perspectives.

5.2 Pastoral livestock systems in Tanzania

In Tanzania the agriculture sector accounts for 27 per cent of GDP and provides a livelihood to over 80 per cent of the population (URT 2006a). Of this, the livestock subsector accounts for around a third of agricultural GDP, with pastoral and agro-pastoral livestock systems producing almost ¾ of the milk and meat consumed in the country (Njombe and Msanga 2010). In addition, the subsector plays an extremely important cultural role for those involved, with owning cattle considered a key way to store wealth. Despite this, few studies of climate change adaptation in agriculture have focused on the livestock sector, in Tanzania or elsewhere.

The vast majority of Tanzania's livestock is held in the traditional extensive systems of pastoralism and agro-pastoralism (see Box 2), which respectively account for 14 per cent and 80 per cent of the country's indigenous cattle (URT 2006b).

Box 2: Forms of pastoralism.

Pastoralism: System of husbandry where livestock graze on unfenced rangelands. Owners are either nomadic (having no fixed abode but moving from place to place in search of pasture) or transhumant (moving between fixed points over the year to make use of seasonal pastures).

Agro-pastoralism: Mixed system of agriculture combining husbandry (where livestock graze on crop-residues and agro-processing by-products, in addition to grazing the rangelands) with cultivation of crops to complement livestock production. Owners are more sedentary than under a pastoralist system.

These two systems are heavily concentrated in the drier northern areas of the country – such as the Morogoro, Kilimanjaro and Dodoma regions (where this study focused) – where the key feature of the environment is its constant inter-annual and inter-decadal variability. The systems are characterised by a number of strategies (see Table 13) that mean they are flexible enough to cope with the highly variable conditions, and in particular periodic droughts, that make settled crop agriculture unreliable.

Table 13: Categories of strategies.

Category	Examples
Managing herd mobility to take advantage of spatial differences in resources	Temporary/permanent migration, herd splitting, land-use planning
Managing herd numbers to better match herd size to available resources	Selling or buying animals, destocking or restocking herds
Managing herd quality to make better use of available resources and make the herd healthier, more productive and more resilient to shocks	Dipping to reduce parasites and disease, use of vet services, changing herd species/breed composition
Managing environmental factors to increase availability and reliability of accessible water and pasture	Building watering points, reseeding pasture, altering burning regime
Diversification away from pastoralism to reduce livelihood dependence on the system	Adopting higher levels of crop-based agriculture or non-agricultural activities

As well as facing pressures from population growth and a general lack of government support (for example, land-use planning that restricts herd mobility), local climate projections suggest extensive livestock systems will be subject to increasing climatic stresses and shocks over the next few decades. In particular, water scarcity is expected to become more severe due to a lengthened dry season and increasing average temperatures. This is likely to exacerbate the effects of climate shocks already experienced by pastoralists who perceive droughts to account for around 75 per cent of climate shocks.

Droughts affect pastoralist systems through several vectors, including lack of available water for animals and reduced production of pasture. These effects result in loss of condition of livestock – lowering fertility and making animals more vulnerable to disease, and hence higher mortality and morbidity. Furthermore, reduced productivity of rangelands during droughts often results in overgrazing and degradation of rangeland. Overgrazing causes rangeland ecosystems to change by encouraging annual grasses and woody perennial scrub instead of perennial grasses, which lowers the productivity and carrying capacity of the rangeland in the long term. There are also further feedbacks on the rangeland system through reduced infiltration of rainwater, increased moisture evaporation, and increased soil erosion.

Many actions that allow pastoralist systems to adapt to climate change are extensions of actions they already take place to cope with existing climate variability (see Table 14). It should be noted, however, that there will be limits to the ability of these adaptation actions to cope with more extreme magnitudes of climate change. At certain extremes of potential climate change therefore, the nature of adaptation strategies may have to change.

Table 14: Coping with climate variability.

Pastoralist action	Form of diversification or risk spreading
Temporary or permanent migration The ability to move herds from areas where pasture is sparse to where it is more abundant is central to pastoralist systems	Spatial diversification
Keeping different types of livestock Cattle, goats and sheep respond differently to environmental pressures. Keeping a mix of livestock types is a form of diversification	Species diversification
Partitioning herds Splits herds into core and satellite herds, which are kept in different areas	Spatial diversification
Maintaining female-dominated herd structure This offsets long calving intervals and stabilises milk production	Keeping spare/buffer resource
Reducing herd size by selling animals to prevent herds exceeding the carrying capacity of the rangeland	Keeping spare/buffer resource
Restocking from fellow pastoralists Following a shock such as a flood or drought, pastoralists restock their herds, often exchanging animals with other pastoralists	Diversification through trade

The study focused on three pastoralist communities. Pastoralists were questioned as to which coping strategies they currently use when experiencing climate shocks. They were also asked which measures they thought they could implement to adapt to climate change in the longer term. Preferences amongst pastoralists for different available coping strategies and adaptation measures varied markedly between different groups (Table 15). There is strong correlation between the strategies groups have traditionally used to cope with climate variability and preferences for future adaptation options, demonstrating the importance of development and adaptation policy taking account of local differences in pastoralist practice and culture, as well as education and awareness raising to introduce new ideas to communities.

Table 15: Climate shock coping strategies: preferences by group.

	Mvomero	Same	Chamwino
	n=44	n=72	n=61
Migration/relocation	54.5	26.4	8.2
Sale of animals	38.6	51.4	44.3
Relief food from government/NGOs	4.5	12.5	19.7
Remittance	2.3	1.4	11.5
Community help	0.0	5.6	1.6
Others	0.0	2.8	14.8

n = number of responses

Through questionnaires and workshops, potential adaptation responses were ranked by the pastoralists. From these exercises a number of adaptation options were established for costing. Table 16 shows the prioritised local adaptation strategies.

Table 16: Adaptation strategy: preferences by community group.

	Mvomero	**Same**	**Chamwino**	***TOTAL***
	n=43	n=35	n=35	n=113
Destocking/harvesting	9.3	20.0	60.0	28.3
Migration	34.9	2.8	2.9	15.1
Diversification beyond the pastoral enterprises	9.3	20.0	17.0	15.0
Restocking/keep more animals	14.0	17.2	5.7	12.4
Collective actions on pasture and water	7.0	22.8	2.9	10.6
Invest in own water points	18.6	2.8	2.9	8.9
Other adaptation actions	6.9	14.4	8.6	9.7

n = number of responses

These adaptation strategies were then put through a filter to combine local, district and national adaptation priorities, resulting in the following shortlist of adaptation strategies that were used as the basis for costing adaptation for this agricultural system. (In addition education and supplying information to pastoralists was identified as a key component of successful adaptation.)

A. **Migration (temporary and permanent):** the research team attempted to break down the costs to pastoralists of moving herds to better pastures. Costs of the movement itself included hiring of trucks for young animals, hiring of labour to assist with trekking the herd, deaths of animals in transit, and the opportunity cost of not milking. In addition, there were costs involved with settling families in the new area and gaining permissions from existing populations. Permanent migration entails reduced costs of movement (the herd only moves one way) but increased costs of settlement.

B. **Watering points:** one way of ensuring a reliable water supply for herds is to build reservoirs to store rainwater and/or dig boreholes to access groundwater sources. The study estimated the costs of constructing such water infrastructure assuming 5000 livestock for three villages, and infrastructure consisting of 1 dam, 3 charco dams and 3 boreholes. Included in this signature was building cattle dips to increase herd health and resilience.[2]

C. **Land-use planning:** land-use planning revisions are required to re-demarcate land for pastoralist uses, and entails costs both in the revision and the implementation of the plan.

D. **Research and training:** knowledge transfer regarding climate change and available adaptation options was thought to be an important component of successful adaptation by the research team. This was envisaged to involve increasing the capacity of pastoralists, extension agents, researchers and policymakers. Costs involve both the ongoing direct costs of extension services and the investment costs to expand the capacity of extension services so that these services can be provided to all who need them by 2030.

[2] A charco dam comprises a pond dug in a flat, semi-arid area and designed to store surface runoff.

E. **Early warning system:** a national system using seasonal rainfall forecasts to predict the state of pasture and available water would assist in herd management and migration planning. The government of Tanzania offered an estimate for the cost of setting up this system of US$180,000, with running costs of 30 per cent of capital cost per annum. The research team considered this estimate to be a gross underestimate, with four times this amount being a more reasonable estimate of probable cost.

Table 17: Costs of adaptation in Tanzania - development deficit and adaptation costs for now, 2020 and 2030 (in million US$).

Planning scale	Actions	Sub-actions	Time scales	Now	y2020	y2030
National	Early warning system	Early warning system	Short term	0.4	3.2	4.8
	Extension training	EW[++] - basic training	Medium term	1.2	11.1	20.8
District	Watering points	Watering points - investment	Medium term	60.7	563.1	1,053.1
		Watering points - R & M	Long term	12.1	112,6	210.6
	Dips	Dip system - investment	Medium term	5.1	46.9	87.8
		Dip system - R & M	Long term	1.4	12.9	24.1
	Land-use plans	Village land-use plans	Short term	3.4	31.8	59.5
		Village land management plans	Medium term	3.4	31.8	59.5
Livestock farmers	Migration	Temporary migration	Short term	84.4	793.2	1,504.5
		Permanent migration	Long term	9.1	84.1	157.2
District	Training	Training: crop agriculture[+]	Medium term	51.9	487.9	925.3
		Training: diversification	Long term	31.2	292.7	555.2
National	Training	Training: EW[++] - climate change	Short term	1.3	11.9	22.2
		Training: policymakers - climate change	Short term	0.1	0.6	1.1
	Research	Livestock research	Long term	17.6	181.2	311.6
			Total	283.3	**2,670.4**	**4,997.3**

[+]*crop agriculture, semi-intensification*

[++]*Extension workers*

R & M = repair and maintenance

National institutional arrangements

Efficient implementation of adaptation in the pastoral systems requires a robust institutional set-up. Functional linkages and hierarchies need to be well coordinated to guide adaptation actions across line sector ministries. Governance of livestock and crop sectors has experienced repeated restructuring in the past three decades. The two sectors used to be under one ministry but are now under two different ministries: the Ministry of Agriculture, Food Security and Cooperatives, and the Ministry of Livestock Development and Fisheries (MLDP), which deals with the livestock sector at national scale – including policy, planning, research and training. (The decentralisation policy has also brought into play the Ministry of Local Government, which is responsible for extension activities in both crop and animal agriculture. This has further complicated the coordination of actions in the two sectors.)

The Ministry of Environment has a full minister but is under the Office of the Vice President. At the moment, climate change issues are handled by the Assistant Director of Environment. This section negotiates climate change funds for the country, and in some cases coordinates funds for climate change activities.

Given the inseparability of the sectors at the grassroots level, the multiplicity of adaptation stakeholders, and the complexities around climate change adaptation, the efficacy of the current institutional set-up remains contentious.

The uncoordinated and parallel efforts may be of little help to the **agro-pastoralists**, who comprise the majority of farmers in the country and who operate their farms as one entity.

The actual amount allocated to the **pastoral system** has increased significantly over the past few years; however the proportion of the budget allocated to pastoralism remains at about 1-2 per cent of the total livestock budget. Since the pastoral system accounts for about 14 per cent of the cattle in Tanzania, the amount of money allocated to the system was 13 per cent, 10 per cent and 10 per cent of its 'expected' allocation for 2007/08, 2008/09 and 2009/10 respectively. This indicates that only small proportion of the budget is allocated to the pastoral system.

5.3 Integrated hill farming systems in Nepal

Agriculture is the mainstay of the economy, accounting for about one third of Nepal's GDP. Employing over 70 per cent of the workforce (CBS 2008), it is not only a source of livelihoods but also a way of life for the majority of the population. However, food security data highlight wide discrepancies between the different regions of the country, with the hill and mountain regions seeing food deficits of 14 per cent and 19 per cent, while the lowland terrain region is 11 per cent in surplus (MOAC 2009). In order to address issues of food security, it is important to understand how hill farming systems work and how to best support farmers to adapt to more variable and extreme conditions expected with climate change.

Integrated hill farming systems

The integrated hill farming system is the main characteristic of the low- to mid-hills of Nepal, which are characterised by terrace farming. The country study focused on the mid-hills, where farming is mixed, diverse and subsistence-orientated, and in which there is a close interaction between crops, animals and forests. Dhading District was used for the case study, with a focus on the Salang and Jogimara village development committees (VDCs). The agricultural land is terraced, with maize-based cropping systems on the higher *khet* land, and rice-based cropping systems in the lower, irrigated *bari* lands. Other crops include millet, pulses, vegetables, mustard, and buckwheat. The integrated and diversified nature of the system provides it with some resilience and ability to withstand a degree of climatic variability.

Farmers cultivate largely for their own subsistence, but may sell small quantities of fruit, dairy products or goat meat in the market to smooth their consumption over a year and to gain an income for non-subsistence items such as education and medicines. The majority of farming households do not have sufficient production to feed their family for the whole year and so migrate for seasonal work over the winter period to supplement their income.

The future of integrated hill farming systems

Integrated farming systems have seen a number of changes in recent years including: a growing preference for rice as a staple instead of maize; land degradation caused by increased use of chemical fertiliser; increased market access and a new preference for growing cash crops; and significant outmigration by the young, with around 1/3 of young people from the two study sites absent at the time of sampling. These factors, combined with government policies that focus on commercial farming and that are largely indifferent to hill farming, pose significant challenges. Climate change adds considerably to these challenges (see Table 18).

Impacts of climate change on the system

Local observations and local climate projections both highlight gradually increasing temperatures, an increase in extreme events, and seasonal shifts. The integrated nature of the farming system means that these climatic changes affect agriculture in complex ways. In particular, droughts during the maize-sowing period affect not only the timing of the maize crop, but also the timing of subsequent crops, which must themselves be harvested before the dry season. Prolonged winter droughts lead to the drying of water sources as well as affecting soil preparation. Heavy rainfall events cause landslides, and hailstorms destroy crops. Irregularities in animal breeding seasons mean forage is not always available at the critical periods. Table 18 shows some of the agricultural changes likely to be induced by climate change in this system.

Table 18: Agricultural changes induced by climate change and socioeconomic factors.

Changes to agriculture	Consequences
Increasing preference for rice instead of millet consumption linked to a preference for cash crops	Movement away from subsistence agriculture to systems with greater levels of market interactions
Increased access to market through new transport systems	Additional options for purchasing and selling of diverse food varieties
Increased trend of out migration and foreign employment, especially by the young population	Increased labour shortage in agriculture; the working burden is predominantly transferred to old people and women. Overall agricultural productivity is also expected to decrease.
Decreased trend of livestock rearing through which the number of cattle has been drastically reduced and been replaced by more profitable hill goats	Reduction in use of manure and increased use of chemical fertilizers, leading to a deterioration in soil quality and water-holding capacity
Enforcement of laws on agriculture inputs has been weakened due to political instability	Quality and price of agricultural inputs and outputs are more variable and uncertain
Increased environmental degradation through increased use of chemical pesticides and insecticides for commercial farming, uncontrolled infrastructure and deforestation	Intensifying climate-induced problems such as change in precipitation, drying up of water sources, warming up of the environment, and soil and water degradation

Coping with climate variability – existing strategies

A range of solutions to these climate change challenges, including sustainable soil and water management practices and the introduction of plastic ponds to store rainwater, are already available. However, knowledge of these technologies has not been widely disseminated and uptake of these methods has been slow. It should also be noted that the integrated farming system already exhibits coping strategies for annual fluctuation in weather by being flexible in the crops that can be grown each year given the prevailing conditions. This will continue to give some protection against climate change, but will be steadily less effective as climate change impacts become more extreme.

Additional adaptation options and their costs

The spread of adaptation options discussed during a stakeholder workshop attended by farmers, local- and district-level stakeholders is shown below in Figure 8. Identification and transfer of the adaptive technologies – mainly regarding varietal and farming practice technologies, and technologies to harvest and use rainwater – have been identified as the priority signatures in the integrated hill farming system. Adaptation in this context therefore places a large emphasis on increasing the effectiveness of extension services and other processes and structures that can support the spread of information regarding available technologies and the results of adaptation-focused research. The agricultural adaptation options should be built on activities that already exist in agricultural plans and thus should be done via an integrated programme approach rather than a piecemeal project approach.

Cost in communities

The unit of the costing done on the community level comprises about 600 households from two villages. The identified total cost does not cover those costs of adaptation activities that are borne by the households privately or autonomously.

Cost in district line agencies

The assumption for calculating the cost at the district level was that at least 40 villages of similar scale implement similar adaptation actions and the district line agencies are then responsible for technical support and coordination. Calculated total cost does not cover the cost of strengthening capacity and coordination.

National cost

Budgeting has been done with the assumption that at least 20 districts will implement the adaptation plan in at least 40 villages each of similar scale to the study sites. Again, the costs for the major adjustment and capacity building regarding the national extension system, and for structural improvement in the institutions for research and extension, are not included in the calculation.

The costs of these adaptation options were estimated using the principles of budgeting, and can be seen in Table 19, below. These estimates are highly sensitive to the assumptions that were used.

Figure 8: Adaptation options: Immediate actions and long-term policy plan (US$).

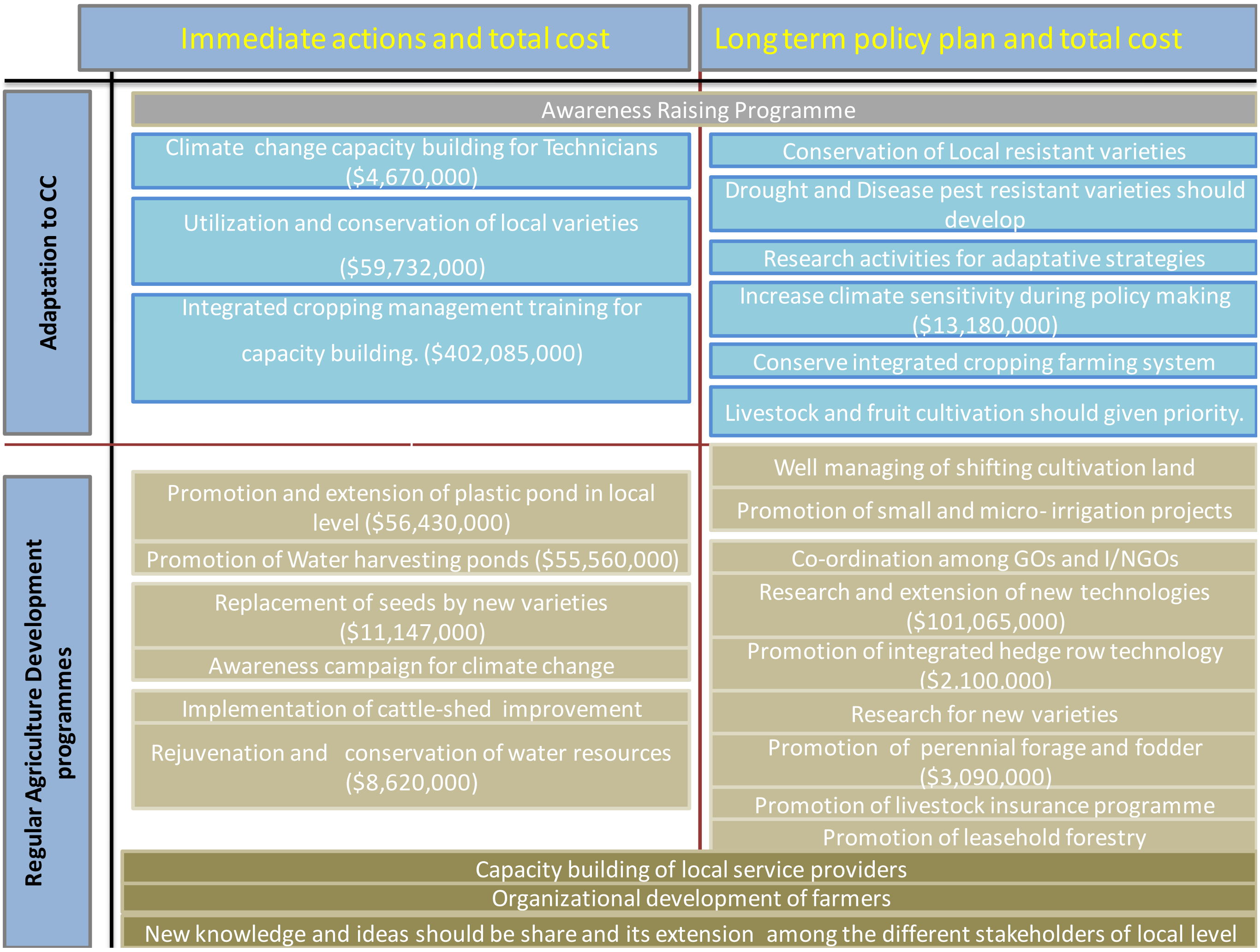


Table 19: Summary of costs for Nepal.

	Now (US$)	Later (US$)
Community: Specific activities in a village of 300 households	40,000	16,000
District: Coordination of local activities over 40 villages	46,000	31,000
National: Coordination of implementation activities in 20 districts of 40 villages each	183,000	410,000

National institutional arrangements

Three ministries were identified as the crucial institutions for agricultural adaptation. These are the Ministry of Environment (the focal ministry for all climate change-related conventions and protocols that Nepal has signed), the Ministry of Agriculture and Cooperatives (for climate change adaptation) and the Ministry of Local Development (responsible for the planning and implementation of activities at the local level). The major constraints for climate change adaptation in Nepal's institutional set-up include:

1. The weak linkages among agricultural research, extension, education and climate information systems.
2. There may emerge a conflict and duplication of roles among the different institutions regarding the implementation of adaptation programmes. The lack of coordination between the Ministry of Environment and the Ministry of Agriculture and Cooperatives (MOAC), particularly concerning their respective cells for climate change issues, hinders the process of mainstreaming climate change adaptation in the agricultural development plans of Nepal.
3. The limited capabilities of the agricultural service delivery agencies.

Currently, there is no programme or project by the MOAC to fund climate change adaptation measures in the agricultural sector. Existing programmes related to adaptation include projects for soil and water conservation, sloping land management, technology transfer, and agronomic trainings.

There are several NGO-funded initiatives, but funding mostly goes directly into projects; furthermore, the extent of NGO-funded projects is difficult to measure and monitor as most NGO funding does not go through official national accounts.

5.4 Adapting to increasing salinity in Bangladesh

Bangladesh is a deltaic country of which 80 per cent comprises alluvial sediment deposited by the rivers that combine and flow out through the delta. Agriculture, forestry and fisheries contribute to 21 per cent of GDP and about a quarter of total exports, and employ just over half of the labour force (BBS 2009). Rice covers almost 75 per cent of Bangladesh's agricultural land and is the dominant crop in the coastal belt of Satkhira, Khulna and Bagerhat districts, where this study focused. Agriculture, especially in the coastal zone, is subject to widespread salinity problems that reduce agricultural output. These problems are expected to increase with climate change.

With a large and growing population, maintaining production in these marginal areas is crucial to food security goals. While a number of climate change hazards need to be addressed, the country study focused on those relating to rising soil salinity levels, because of their particular importance to the agricultural system.

Currently, 35 per cent of Satkhira District, 29 per cent of Khulna District and 36 per cent of Bagherat District is classified as either 'Strongly Saline' or 'Very Strongly Saline' (i.e., above 8dS/m), where crop production is almost nil; an additional 5, 7, and 8 per cent of land is 'Slightly Saline' (4 - 8dS/m), where many crops find it difficult to survive.

Drivers of salinity

Bangladesh experiences a cycle of saline intrusion and outflow through the year, with sea water flowing further into the delta during the dry season (November to May) which is then diluted out with fresh water during the wet season (June to October). Saline groundwater also is brought to the surface during the dry season. Tidal action means low lying land is constantly inundated and uncovered. As saltwater on land evaporates away the salt content is left behind.

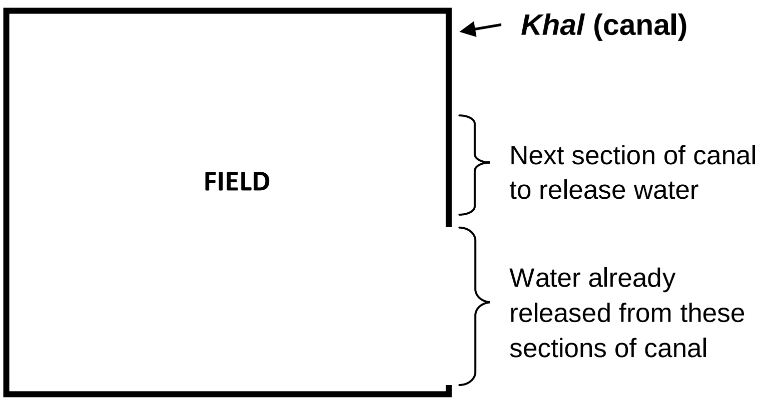
Climate change is expected to change the hydrology of Bangladesh through several vectors further increasing the salinity in the soil. Sea level rise will result in saltwater intruding further into the coastal zone and increases the probability of saltwater overtopping protective bunds into fields. Sea level rise may also result in greater salinity in groundwater sources, reducing the availability of freshwater for irrigation.

Changes in the timing and intensity of the monsoon are expected to result in a shorter but more intense wet season. Melting of snow and ice in the Himalayas will change the freshwater flows through river systems as will adaptation actions by India to store and utilise more of the water from the Ganges, reducing freshwater flows to Bangladesh. Generally it is expected that saltwater will intrude further into the country and the availability of freshwater for irrigation and to leach salt out of the soil will be reduced.

Existing adaptation

Agriculture in the coastal zone of Bangladesh has already adopted various measures to allow it to cope with existing levels of salinity. Bunds are built around fields to prevent saltwater inundating them at high tide. Drainage channels (called *khals*) are built around fields to capture freshwater during the annual floods of the wet season. *Khals* allow farmers to release freshwater into their fields, individual canal sections at a time, to flush out the salt that would otherwise build up in the soil (see Figure 9).

Figure 9: *Khals* in Bangladesh.



A system of drainage ditches allows brackish water from irrigated fields to drain away. Furthermore, Bangladesh has been at the forefront of global efforts to breed varieties of rice that can still grow in saline soils.

Whilst some adaptations have already been adopted, there is still currently a development and adaptation deficit; there is more which could be done to cope with existing environmental pressures. This deficit will be compounded by climate change. Existing methods for coping with salinity will have limits to their effectiveness if salinity levels rise too far. Currently, however, there is still scope for expanding existing practices; limits have not yet been breached.

Adaptation signatures

The study looked at two main adaptation signatures to cope with rising salinity. These are the development and deployment of saline resistant varieties; and improving irrigation, drainage and flood defence infrastructure to improve capacity to irrigate crops, leach out salt, and protect against seawater intrusion. The study looked at the costs of the various types, scales and incidences with respect to existing actions, and then attempted to estimate them as they are scaled up to cope with increased climate change-induced salinity.

Saline-resistant varieties

There are multiple aspects to operationalising the use of saline-resistant rice varieties. The variety needs first to be developed by one of the several research institutions within Bangladesh; the seeds then need to be distributed to farmers. In addition, knowledge regarding the existence of the improved seeds and changes to cultivation practices needs to be disseminated. These three interlocking systems (research and development, distribution, knowledge extension services) are all required for the adaptation signature to be effective.

Building improved defences, irrigation and drainage

Bunds to keep saltwater out of fields at high tide and during floods, and channels allowing drainage of water used to leach out salt, comprise important infrastructure for keeping salinity levels tolerable. Actions to improve infrastructure at the farm level are typically performed by farmers, however this obviously only represents local-scale activities and a more coordinated national approach is probably needed. Costing such local action in monetary terms is very difficult since the monetary value of local, unpaid labour is difficult to quantify. While the research team recognised the importance of local infrastructure they did not attempt to quantify it.

Costing adaptation

As with costing of adaptation in many settings, it is very difficult to break down costs between climate change adaptation and development for the institutional actors. The agricultural research and extension institutions are attempting to improve food production and availability given several constraints, of which climate change is one aspect. Even without increasing climate variability into the future, research to improve farming practices and yields would be necessary. Many of the activities these institutions are engaging in do have a positive impact on adaptation, but these activities cannot be entirely characterised as climate change adaptation actions.

Furthermore, the costs of strengthening institutions over the next 20 years are very sensitive to the growth rate assumed for these institutions. Annual costs estimated for now and for 2030 are shown in Table 20 below.

Table 20: Adaptation costing for Bangladesh.

	Now (US$)	Later (US$)
Local: awareness and demonstration in three districts	827,000	2.5 million
District: agriculture marketing, grain storage, insurance, credit linkages	819,000	7.3 million
National: rice research and dissemination, variety improvement, biotechnology research, impact assessments, agriculture sector development	10.3 million	32.4 million

National institutional arrangements

Bangladesh has a very complex agricultural institutional framework, with as many as 12 departments and institutes falling under the Ministry of Agriculture that are relevant for various aspects of agricultural adaptation. While this is desirable to ensure that all adaptation and food security functions – from production to utilisation – are covered, it may lead to system complexities that slow down implementation, or the absorption of adaptation funds by bureaucratic functions. Because the stakeholders consider the development of saline-resistant varieties as the main adaptive measure required to address salinity, most of the actions lie with government institutions responsible for these developments. There are, however, other land husbandry and marketing-related activities that are also required at the local level, but their costs are very low compared to national costs.

The key issues in planning the adaptation of Bangladesh's agricultural system that were considered in the country study are:

1. The capacity building of institutional/relevant government and non-government authorities to implement activities at all levels efficiently and effectively.
2. Building on proper coordination among different relevant government agencies and also among agencies (inter and intra) to actually get work done successfully.
3. Part of the fund allocation must support research initiatives both by the government and non-governmental organisations.
4. Monitoring, evaluation and supervision to follow up and scale up activities at all levels through an independent body comprising government and non-government representatives/experts within both national and sub-national administrative structures.
5. Farmers are using extensive traditional knowledge in regards to adaptation. Advanced scientifically-tested techniques should be disseminated in order to gain better results. This must be addressed using awareness-raising exercises, namely training programmes.
6. The costs of using 'climate-smart' varieties are equal to those of traditional varieties. This will allow the user (farmer) to adapt to resilient technology efficiently.

5.5 Coffee in Rwanda

In Rwanda, agriculture contributes to over a third of GDP, employs more than 80 per cent of the workforce, and supplies 90 per cent of the nation's food. Coffee is a key crop, not only providing cash incomes for some 500,000 Rwandan families (almost one-quarter of the national population) (NAEB 2005), but also because it is the country's top export and chief source of foreign exchange income (Tobias and Boudreaux 2009). Coffee is grown by smallholders in fragmented pockets on just 6.3 per cent of Rwanda's cultivated land. There are no large-scale mono-crop coffee plantations in Rwanda. Crucially, the high quality of Rwandan coffee, which is as much a result of the processing procedure as of the favourable soils and climate, means it is able to command premium prices on international markets. Maintaining both the quantity and quality of Rwandan coffee in the face of climate change necessitates an assessment of actions required at all stages of the supply chain.

Although coffee is grown across the whole country, its production is highly dependent on soil, topography, and climatic conditions (as well as local socioeconomic factors), and as such the quantity and quality of coffee production varies across the country. The study considered three sites – Nyanza District (south-eastern study site), Nyamasheke District (western study site) and Huye District (southern study site), which each grow varieties suited to the local conditions – in order to take into account these differences.

The genocide of 1994 has had a lasting effect on Rwanda. The knowledge and skills in many sectors are still recovering and being rebuilt. It should be noted that developments in coffee production in Rwanda have occurred almost entirely in the past decade. Prior to 2001, Rwanda produced no fully washed coffee and did not participate in high value global speciality coffee markets.

Coffee-climate linkages: farm level

Ideal conditions for growing Arabica coffee are temperatures of 18°C at night and 22°C during the day. Temperatures above 25°C reduce photosynthesis and temperatures above 30°C can damage blossoms and result in fruits with defects. Climatic changes may also have an effect on the incidences of various diseases that reduce crop quantity and quality.

Rainfall patterns affect the coffee crop, with long dry periods detrimental to coffee production. The concentration of rainfall into a shorter, more intense, wet season increases soil erosion and makes maintaining an adequate water supply to the coffee bushes more difficult. The patterns of rainfall also influence when the coffee flowers and the cherries ripen. Whilst moisture is important, sunlight is also an important variable in respect of how coffee grows.

The level of atmospheric humidity is important; low humidity increases evapo-transpiration of the bushes but very high humidity adversely effects coffee quality. Sixty per cent relative humidity (RH) is ideal. RH which is persistently above 85 per cent reduces coffee quality.

Coffee-climate linkages: processing

Climate-related variables are also important in some aspects of the post-farm processing. Coffee beans are generally sun-dried, so rains in the harvesting season slow the rate at which coffee washing stations (CWSs) can process harvested cherries. In addition heavy rainfall can cause mudslides in the mountainous terrain where the coffee is grown. This can adversely affect roads and delay the movement of harvested to the CWSs, contributing to diminished quality. These types of challenges are likely to increase under a changing climate.

To a significant extent, the value of coffee at the farm gate is dependent on the capacity of the processing system to process cherries quickly and to a high standard after they leave the farm. The maintenance of high quality coffee production at farm level can only realise a premium if there is sufficient capacity in the post -arm processing system.

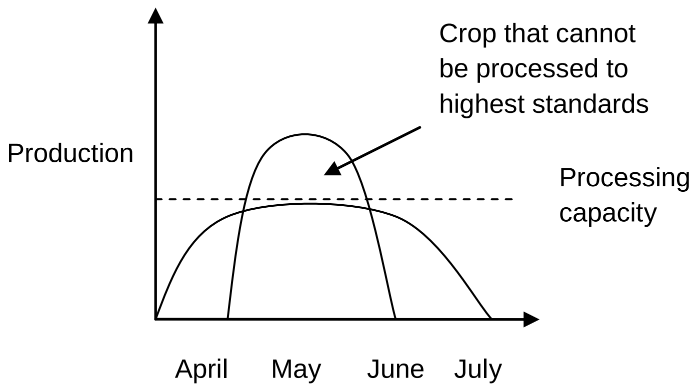
Adaptation and development

Improvements in the coffee sector are seen as a significant pillar of Rwandan national development plans. The coffee sector benefits from strong political support, which is unlikely to wane in the near future. Policies emphasise land consolidation, intensification, improved water management, coffee storage and transport, and the availability of agricultural finance and credit – striving towards a modernised agriculture that is competitive in speciality markets. A changing climate poses additional challenges in achieving this.

Changing climatic stresses and shocks affect the timing of coffee production. Farmers have already noted that the June-August dry season is lengthening, and that this is causing a delay in the flowering of the coffee. The heavy rains expected in March have reduced in intensity, meaning the cherries do not start to ripen until April. Non-systematic shifts of climate variables are facilitating the migration of pest and disease.

Coffee washing station owners emphasised that in years with poor rainfall, the harvesting period was shorter, resulting in a higher peak in production that meant they are not always able to process all the coffee to the standard required by the speciality coffee market, as seen in the figure below.

Figure 10: Production of coffee cherries over the harvesting season.



Adaptation to climate change and general development in the coffee sector are very difficult to separate. In the processing system, adaptation and development generally take the form of greater investments in processing capacity through building more CWSs and improving roads. It must be noted, however, that the shortening of the coffee harvesting season means that processing capacity will be lying idle for a greater proportion of the year. This will reduce returns on investment unless a corresponding increase in quality can be secured to offset the shorter season.

At the farm level, adaptation and development take the form of better distribution of inputs – including fertiliser and pesticides, investment in capital such as spraying equipment, and improved extension services to raise farmer knowledge and skills. It is hoped that this will reduce losses (both quantitative and qualitative) from disease and pests, and maintain better soil quality.

As well as direct investment in the coffee production and processing system, the need to have better functioning institutions to coordinate development and adaptation actions was recognised. Such institutional investments, which would significantly improve coordination and adaptive capacity, are shown in Table 21 below.

Table 21: Annual adaptation costs estimations for now and in 2030 (in US$).

Action	Actor(s)	Cost/$ now	Cost/$ 2030
1. Creation of prestigious and knowledge-based Centre of Climate Change Economics and Agriculture Development	1. Government (Ministry of Finance and Economic Planning) 2. Donors and civil society organisations: the GoR should plan strategically in interesting and mobilising these partners to allocate money in the establishment of the Centre	5,700,000	20,000,000
2. Research, development and distribution of new varieties adapted to new climatic conditions	1. Rwanda Agricultural Research Institute (ISAR) 2. Donors, civil society organisations	1,000,000	15,000,000
3. Intensification of infrastructure development in rural areas	1. Ministry of Agriculture and Animal Resources; Ministry of Infrastructure 2. Donors, civil society organisations	4,000,000	40,000,000
4. Disaster relief preparedness	1. Ministry of Disaster Management and Refugee Affairs 2. Donors, civil society organisations	2,000,000	40,000,000
5. Wastewater treatment plan and watershed management	1. Ministry of Environment, Ministry of Agriculture and Animal Resources, and Ministry of Infrastructure 2. Donors, civil society organisations	1,500,000	15,000,000
	Total	**14,200,000**	**130,000,000**

As well as institutional and coordination costs, there will be a number of areas of direct investment in coffee systems that should support both adaptation and development. It should be noted, however, that these are combined adaptation and development costs. Despite the best efforts of the country team, separation of these costs was not possible.

Table 22: Additional direct investment needs.

Action	Actor(s)	Cost/$ now	Cost/$ 2030
1. Implement turnaround programme for CWSs to improve their productivity and profitability, including wider application of the post-sale premium payment schemes	1. OCIR-Café 2. CWS owners	500,000	2,500,000
2. Support the operationalisation of the Coffee Marketing Alliance, including systems of quality control, and the Cup of Excellence® Program. Create additional value-added activities, e.g., toll roasting, and partnerships and relationships with major buyers abroad	OCIR-Café	500,000	2,500,000
3. Toll roasting, and partnerships and relationships with major buyers abroad	OCIR-Café	500,000	2,000,000
4. Carry out adaptive research on coffee varieties (e.g., Panama from Ethiopia)	ISAR	300,000	1,500,000
5. Replace old coffee plantations with plantings of new varieties that are of better quality and are more disease-resistant, and develop multiplication centres for new seedlings	1. OCIR-Café 2. ISAR	700,000	4,000,000
	Total	**2,400,000**	**12,500,000**

National institutional arrangements

The market orientation of the coffee system in Rwanda makes it a specialised system, subject to both market and non-market signals for its adaptation. Even though government has a policy for promoting coffee production, the day-to-day activities are run by specialised parastatals that derive their revenues from coffee. The advantage of this arrangement is that market mechanisms can be followed easily to both improve system performance as well as its adaptation to climate change. The disadvantage is that the system would often be overlooked in national adaptation policies, which could leave thousands of smallholder producers vulnerable to climate change.

There is an opportunity for cross-institutional coordination in Rwanda through the Agriculture Sector-Wide Working Group, which brings together the different agricultural agencies for specific crops in the country. This working group has been instrumental in harmonising activities and contributing to a shared vision with the effective collaboration of implementing agencies, donors and support agencies and key stakeholders. The country study showed that rapid progress and success has been achieved under the programmes of the Ministry of Agriculture and Animal Resource's PSTA II (Second *Strategic Plan for the Transformation of Agriculture*, 2004) initiative. It is through such a platform that agricultural adaptation in different systems could be promoted.

Market-based adaptation opportunities are greatest in Rwanda as coffee is exported, and fair-trade-related routes could be used to channel private sector adaptation funds to this system. Similarly, low carbon agricultural development has potential in the coffee system as there are vast opportunities to improve its efficiency in production and processing. Rwanda is one of the countries that has taken early steps to explore low-carbon development opportunities.

Like most countries, one of the institutional weaknesses in Rwanda is the separation of climate change lead agencies from other sectors, which leads to the current lag between policy and implementation.

5.6 Subsistence rainfed food production in Malawi

In Malawi the agricultural sector contributes about 39 per cent of GDP and more than 90 per cent of the foreign exchange earnings, supplies more than 65 per cent of the manufacturing sector's raw materials, and makes up 87 per cent of total employment (DAES 2000). The smallholder subsector, which is based on customary land tenure and is primarily subsistence, contributes more than 70 per cent to agricultural GDP, with the remaining 30 per cent ascribed to large estates growing tobacco, sugar, tea, coffee and tree nuts.

Subsistence rainfed food production
The main subsistence crop is maize, and it is cultivated twice a year by households along the Shire River and once a year by those in upland areas. Maize is the main staple in Malawi and grown on two-thirds of the country's arable land, largely on smallholdings of 0.5 – 0.8 ha. It is grown during the rainy season (November to April), but communities along the Shire River also grow it after this season by taking advantage of residual moisture. Due to increasing flood incidences, farmers now rely more on this residual moisture than in the past as these floods also bring in nutrients from the upland regions; this increases soil fertility, reducing the need for additional fertilizers to maintain soil nutrients.

Depending on their geographical location, farmers grow either one or two maize crops over a year (see above) alongside a range of other subsistence crops – including cassava, sweet potato and beans. Small amounts of cash crops (such as tobacco) are cultivated and a small number of livestock are kept. Additionally, poor rural households obtain around a third of their income from 'off own farm' activities (Kydd *et al.* 2004), including as seasonal labour in the estate sector. The Malawian farming system is also characterised by poor backward linkages (e.g., uncoordinated input supply) as well as limited access to technologies, extension services and credit.

High temperatures (of up to a maximum of 37.2^{o}C in November) and unreliable rainfall ranging from 170 - 968mm per year mean water availability is often a limiting factor for agriculture in Chikwawa District, in the south of the country, where the country study focused. Although the diversified crop base and the use of drought-resistant and early-maturing varieties help farmers withstand climate variability in the form of droughts and floods, the system's dependence on rainfed crops means it remains vulnerable to variations in weather, as well as to commodity price shocks.

As well as general trends of increasing temperatures and delays in the rains, the magnitude and frequency of both droughts and floods have increased over the past two decades, with farmers noting that droughts and serious floods now occur every two to three years. While floods have devastating immediate impacts (including the loss of lives, livestock and crops) the residual moisture allows them to grow more crops over subsequent months. The farmers therefore highlighted that droughts pose the greatest threat to food security, particularly as they affect both crops and livestock over a broader area, which means that it is often not even possible to buy food in neighbouring villages. These types of impacts are likely to increase in number and severity as a result of climate change.

Existing coping strategies for spreading the risks of climate change effects depend on the duration of the hazardous climate change event and range from eating wild tubers (*nyika*) from the Shire River to temporary migrating out of the area to seek food and water. However the most common strategy was casual labour (*ganyu*), involving short-term rural employment relationships that provide additional income, which could be used to buy food. (This strategy was commonly independent of the length of the climate change hazards.) However, during short drought incidences, households resorted to replanting their maize crops. In longer droughts they focused on different strategies such as irrigation and migration. Irrigation is especially common for communities along the Shire River.

The future of subsistence rainfed food production
Over the past decade, a number of policies have been introduced that indicate that the farming system benefits from broad government support. In order to address food security issues, particular large scale input subsidies were re-introduced at the start of the 2005/06 agricultural season. The 2010 Greenbelt Initiative also seeks to support agriculture by introducing irrigation along the shores of Lake Malawi and the Shire Valley. However, subsistence rainfed food production – in Chikwawa District in particular – faces a number of challenges if it is to meet food security demands over the coming decades.

Adaptation options
The range of strategies farmers currently use to withstand droughts – for instance relying on food aid, eating wild tubers, engaging in casual labour, and temporary migration – shows how the system is struggling to cope with the adverse effects of climate change and indicates that new and additional measures will need to be employed to generate effective adaptation. One interesting emerging trend is the growth in land rental markets along the Shire River, which allows families who are based 20km away to grow maize crops in the dry season by using the residual moisture following the flooding of the river.

Other measures that can support local communities to adapt to climate change include assessing land tenure laws (crucial to development of the land rental market) and increasing the farmers' market linkages, which would allow them to increase their income and thereby reduce their vulnerability to climate change.

Technologies such as drought-resistant crops and animals, irrigation, and rainwater harvesting each play potentially significant roles in reducing the vulnerability of subsistence agriculture in Malawi to droughts. This requires further research and investments in extension services to allow the technologies to be disseminated more widely, as well as investment in the inputs – in particular the materials – required for their implementation. Furthermore, greater coordination between government and NGO activities is crucial for this process; a suggestion that arose out of the country study was to establish an institution responsible for coordinating climate change adaptation actions (see Table 25).

Box 3: Malawi farming system.

Subsistence rainfed maize production in Malawi is characterised by small landholding size (0.5 - 0.8 ha), continuous cultivation of maize on the same land without adding organic or inorganic fertilizers, low productivity (which will get worse with the effects of climate change), and high dependence on rainfall. However, communities along the Shire River, such as the Chikwawa District farmers, use two sources of water: rainfall, and the residual moisture following the regular flooding of the river, which allows a second maize crop to be grown in strips of land along the river banks.

Table 23: Coping with climate variability, especially drought.

Coping action	Form of diversification or risk spreading
Food aid is already provided during very short drought incidences.	Resorting to government / NGO / international support
Buying food becomes more relevant the longer drought periods last.	Moving away from the subsistence farming system
Eating wild tubers (*nyika*) from the Shire River.	Resorting to ecosystem services / dietary change
Selling assets becomes more relevant the longer drought periods last.	Drawing down value from capital assets
Temporary migration to seek employment, food and water is conducted in cases of longer drought periods.	Spatial diversification
Engaging in casual labour (*ganyu*), which incentivises people to migrate and provides them with an additional income. This strategy occurs for all durations of climate change hazards.	Income diversification
Replanting maize crops is commonly applied during short drought incidences.	Seasonal diversification
Implementing irrigation systems is performed for longer drought periods and is common, especially for communities along the Shire River.	Technological diversification from ecosystem service

Table 24: Suggested future actions.

Assessing land tenure laws to further facilitate growing of crops during the dry season.
Increasing market linkages for farmers.
Increasing capacity building through extension services.
Developing technologies such as drought-resistant crops and animals.
Increasing livestock production.
Improving irrigation and rainwater harvesting technologies.
Promoting further research as well as investments in inputs and extension services.
Facilitating a wider dissemination and effective implementation of climate-resilient technologies.
Enhancing cooperation among governments and NGOs (for instance, through the establishment of an institution responsible for coordinating climate change adaptation activities).
Promoting village saving banks.

The total adaptation costs for the Malawi system were estimated for the different functions to be performed by different actors, including the private sector. These are shown in Table 25, below.

Table 25: Summary of adaptation costs.

	Government	Private sector	NGO	Farmers	TOTAL
	US$	**US$**	**US$**	**US$**	**US$**
Linkage to markets (promoting market access) (10,000 households)	1,576,885	30,000,000	1,000,000	100,000	32,676,885
Development, multiplication and promotion of improved drought-resistant varieties	32,714				32,714
Drip kit for 0.2 ha of land for one household = US$1,000/household (10,000 households)	10,000,000				10,000,000
Labour contribution to construction of tanks = US$2,000/tank (1,000 tanks)				600,000	600,000
Cost of one underground tank materials = US$2,000/tank (1,000 tanks)			2,000,000		2,000,000
Cost of one earth dam = US$10,000/dam (assuming 200 earth dams across the whole country)	2,000,000				2,000,000
Institution established that coordinates activities in climate change adaptation	21,000				21,000
Research in advanced irrigation technologies, e.g., solar as a source of energy for pumping water, and underground pipes	1,254,333				1,254,333
Increased livestock production	1,450,000				1,450,000
Promote conservation farming/agriculture (all technologies that maintain soil fertility and water management) = US$500/household (10,000 households)	5,000,000				5,000,000
Total	**21,334,932**	**30,000,000**	**3,000,000**	**700,000**	**55,034,932**

National institutional arrangements

Malawi has a wide range of programmes and plans at national level that deal with climate-related constraints in some capacity. At the local level, the country also has various government and NGO projects addressing climate-related issues (mostly droughts and floods) even though these are not necessarily conceptualised as adaptation projects. What is interesting is that most of the proposed adaptation actions do not differ from current activities, many of which are not categorised as adaptation projects.

While there is an evident separation between climate change institutions and agricultural institutions, there is a significant recognition of the vulnerability of agriculture. Consequently, the country's National Adaptation Programme of Action (NAPA), contains several agriculture-related strategies such as:

1. Improving community resilience to climate change through the development of sustainable rural livelihoods.
2. Restoring forests in the Upper and Lower Shire River to reduce siltation and associated water flow problems that affect hydropower generation.
3. Improving agricultural production under erratic rains and changing climatic conditions.
4. Improving Malawi's preparedness to cope with droughts and floods.
5. Improving climate monitoring to enhance Malawi's early warning capability and decision making.

This is mostly explained by the fact that Malawi has in the past followed highly consultative planning processes that involve different stakeholders. Significantly, Malawi has also developed an agricultural development programme under the Comprehensive Africa Agricultural Development Programme (CAADP) of the New Partnership for Africa's Development (NEPAD). This and other programmes have a strong focus on addressing the constraints facing Malawi's agriculture, which is a natural starting point for building adaptive capacity.

Malawi receives significant external support, and has developed mechanisms for channelling funds to different sectors through the Ministry of Finance. The complexity for agricultural adaptation brought about by the separation between the climate change line ministry (Ministry of Environment), the Ministry of Agriculture, and the Ministry of Transport (in which the Meteorological Department is housed), requires that a mechanism for sourcing climate finance and deploying it to the identified adaptation activities at all levels be well coordinated. This is especially important if the most important and most immediate adaptation actions required for the country fall within the agricultural sector.

The development of Malawi's maize sector has been significantly attributed to the country's subsidy programme, which has channelled resources to smallholder maize farmers. With or without external resources, it is important that these programmes incorporate climate adaptation to avoid maladaptation and locking smallholder farmers into single crop systems.

The role of the private sector is quite significant in Malawi, especially in market linkages, which suggests that that adaptation and food security responses required in the country go beyond just production to include access and utilisation. Market linkages could also be a way of building a strong, community-wide and community-district-national adaptive base that does not solely depend on the level of production of individual households. The role of the private sector was also evident in the case study research when the sugar company in the case study community provided the time-series weather data that was used for downscaling climate models.

5.7 Issues cutting across case studies

The pathways that are evident in the adaptation signatures from all the case studies show an overlap or a transition from current agricultural development efforts (and addressing climate change variability) to specifically adapting to climate change. However, in the single crop-focused signatures of Rwanda (coffee) and Bangladesh (rice), the distinction between agricultural development and adapting to climate change is less evident, even in the long term, except in respect to institutional strengthening. In Bangladesh, research into saline-resistant rice varieties has been going on without reference to climate change, while the need to strengthen the coffee value chain in Rwanda is already evident, without the imposition of the climate constraint. The implication of this focus on existing needs is that countries need to look beyond these solutions, especially in the long term, since the solutions do have their limits (e.g., a limit to rice variety salinity-resistance beyond a certain point). This will require other adaptation measures.

The adaptation signatures and their associated costs are all dependent not only on the system, but on the policy and institutional framework in each country, the extent to which it is devolved to the local level, the extent to which it provides for the involvement of other actors outside government, and the cross-linkages among government institutions.

Across all countries, institutional mechanisms for implementing agricultural adaptation need to create harmonisation between the institutions responsible for agriculture, climate change, and local development and governance. Agricultural ministries seem to have the overall strength of having presence at the very local level, but at the national level they do not actively participate in climate change policy processes.

There is also a clear lack of clarity on the role of climate information institutions at all levels, showing the low priority given to accurate scientific climate change information in developing countries. Although it is clear that countries are not aware of the exact future climate scenarios in the long term, there seems to be a common tendency in all countries to base all adaptation on just the fact that the climate is changing and the experiences of floods and droughts that they are experiencing. This has implications for the extent to which plans for the long-term future could be made and the appropriateness of specific long-term adaptation actions. This however, is addressed to an extent by the fact that most long-term adaptation options seem to give primacy to research and capacity building.

NGO projects constitute a significant portion of the ongoing adaptation actions in several countries, although some of these are not necessarily conceptualised as climate adaptation projects. The variety of these projects and their coverage suggests that even within the same local community (e.g., in Chikwawa District, Malawi) different approaches will be used by different households, and households often use a range of different adaptation or coping measures at the same time.

5.8 Boundaries to the research

In any research project it is essential to establish appropriate boundaries for assessment. These should be wide enough to result in research that captures the main drivers and nature of the system under examination. They also must be narrow enough, however, to keep the assessment manageable and to exclude areas which, though possibly interesting and related to the main assessment, will not significantly further understanding. The added complexity of a wider assessment may produce more 'noise', reducing the clarity of the key findings.

This project was bounded in three main ways: the choice of five case study systems; the ways in which the country teams incorporated the multiple functions of the agricultural systems that were the focus of each of their studies; and the implications that this had for estimating costs.

Choice of case study systems
The five agricultural systems studied do not represent all of agriculture around the world, nor in fact do they represent agriculture within the specific countries. They do however show a selection of examples of how agriculture may adapt to climate change in different circumstances, highlighting the heterogeneity of agriculture as much as any similarities. This compounds the need to consider agricultural adaptation at this level, and highlights the need for research into agricultural adaptation across a much greater number of agricultural systems.

Complexity of agricultural systems
The agricultural systems this project studied are complex and comprise multiple processes, actors and functions. In particular, they are intimately integrated into environmental and social systems in all the developing countries covered by the project. Climate change impacts on the agricultural systems can be expected through many causal chains, which can be expected to interact in complex and unpredictable ways.

In general, each of the case studies considers a single or limited number of crops in a specific type of geographical location currently being farmed with specific technology. These constitute the 'defining' and 'associated' properties for each case study and are a good definition of assessment boundaries.

The extent to which the country teams incorporated these different aspects of the systems varied depending on what are considered to be the critical components involved in agricultural adaptation in each of the specific settings.

Each of the case studies showed that climate change adaptation happens on many different but interacting spatial scales simultaneously. Additionally, certain adaptation actions highlighted as being part of adaptation pathways for each system are conducted by individuals outside of the agricultural system (for example, local and national governments). These actions are considered for the purposes of this assessment to be relatively autonomous to the agricultural systems considered. The adaptation pathway framework is designed to capture moments of possible interventions against this grounded reality of actors acting at multiple scales, seeking several key objectives, and constrained by environmental, economic, social and institutional factors.

Costing
Although country teams participated in an initial project inception workshop and were supported in using a single methodology, the application of that methodology varied between countries due to context and therefore allowed country studies to adapt to the specific needs of the individual study in question. Application varied by the emphasis put on local and institutional actors, by the adaptation measures costed, and because each team was assessing a very different agricultural system. As such, none of the cost estimates can be considered complete or comprehensive, nor can they be compared with each other. The costs estimates were in many cases only applicable to the region in the country in which they were derived. Scaling them up to wider regions, or indeed globally, or transferring values to use these data in economic analyses in different countries, would create many problems and is not recommended by the research team.

The cost values are highly sensitive to changes in the assumptions that back them up. For example, the Tanzanian team have assumed that average annual growth rates observed since 1990 (5.6 per cent) will be maintained over the next 20 years. The use of such an estimate may well be, in and of itself, the best estimate available. However, the use of such a figure comes with a 'past performance is no guarantee of future results' type of warning. Such a growth rate indicates that herds nearly triple in size every 20 years; an outcome which is likely to be not possible or desirable in Tanzania due to associated problems of over-grazing and rangeland degradation.

Such problems of compounding growth rate assumptions were also found in estimates of how quickly institutions, especially extension services, would have to expand to meet adaptation needs over the next 20 years. In the event that the bold expansion rates for institutional expansion do not occur, this has a significant impact on both the costs and effectiveness of adaptation.

Closely linked to the issue of expected growth rates for each case study is the question of what size of system we are looking to adapt This is linked to deeper socioeconomic questions, for instance will subsistence agriculture be as prevalent in 20 years time as it is today? Will the majority of developing world farmers engage in small-scale activities on small plots of land or will these be transformed to become larger farms with greater levels of mechanisation and inputs? The future nature of agriculture has a huge bearing on the adaptation costs that will be faced. This is another example of assumptions that assessments of the costs of adaptation need to make – many possible assumptions are equally valid but have a huge effect on the final estimate produced.

6. Evolving global policy processes for agriculture and climate change

6.1 Introduction

The close relationship between agriculture and climate change is receiving increasing attention at the global level, but mostly outside the official UNFCCC processes. Despite agriculture being recognised as one of the sectors most affected by climate change (e.g., IPCC 2007), and the fact that the majority of developing countries depend on it to sustain their economies and populations, there has not been a specific formal focus on agriculture (as, for example, there has been on forests). The recognition of the current and potentially significant contribution of agriculture to greenhouse gas emissions is, however, becoming a strong driver for getting agriculture into the UNFCCC processes – for example, the submission by the FAO in 2010 to the UNFCCC for a work programme to be initiated under the Subsidiary Body on Scientific and Technical Advice (SABSTA). Food security is also a key motivation for several global platforms and processes to get agriculture 'on board' climate change debates, directly and indirectly. These processes and platforms form part of the basis for considering how agriculture could be part of a post-2012 climate change deal.

Section 6 provides an overview of emerging global policy processes that are likely to influence country-scale action on agriculture and climate change. Specifically, this section outlines some of the emerging discourses at the global level around climate change and agriculture. It outlines the types of actions that are being put on the table to foster adaptation and mitigation in the agricultural sector; the main factors driving this process; and the main avenues being used to drive it.

The key global processes analysed here are components of the UNFCCC negotiating framework that sets the policies and priorities for climate responses, agricultural research, and the development community (as well as the private sector). The donor community cuts across these three spheres. Analysis of these spheres and processes provides initial perspectives on how their respective contributions could be harnessed and harmonised to deliver an effective agricultural adaptation response that taps into their respective advances. Indeed, a multiple-stakeholder approach at the global level is equally as important as it is at the local level. A coordinated global policy environment sends clear messages that guide effective responses at country levels, and makes best use of limited adaptation resources.

6.2 UNFCCC discourses around climate change and agriculture

The impacts of climate change (CC) will undermine agricultural systems in a number of ways as outlined earlier and in the country studies. In terms of climate change, for instance, climate-induced changes in temperature, precipitation and the occurrence of extreme weather events are already leading to changes in agricultural productivity. Similarly, given that agricultural systems contribute global to GHG emissions, emerging climate change policies around mitigation and low carbon development are likely to demand changes in agricultural systems.

Recognising the relationship between climate change and agricultural systems, emerging global policy discourses focus largely on 'resilience' and 'climate-smart agriculture'.

Climate-resilient discourses
Resilient agricultural systems, as opposed to intensive growth-focused agricultural systems, constitute an emerging discourse in response to climate change. This discourse recognises that in order to maintain or enhance agricultural growth objectives, agricultural systems will

need to be resilient to the impacts of climate change. In India, for example, the future *12th Five Year Plan* (2011) incorporates a focus on resilience by aiming to ensure 'inclusive low carbon growth'. In global policy discourses, the outcomes of the NAPA process that are of relevance to agriculture also put a spotlight on 'resilience' as opposed to 'economic growth'. For instance, agriculture is the most prioritised sector in the NAPA process (see Figure 11, below). Within the agricultural sector, an analysis of NAPA priorities in the food security sector indicates a broad trend in terms of resilience objectives. For instance, country priorities related to food security include: sustainable production; livelihood and agriculture diversification; research and development of climate-resilient systems; and improved access to climate data (Table 26).

Figure 11: Sectoral priorities in the NAPA process.

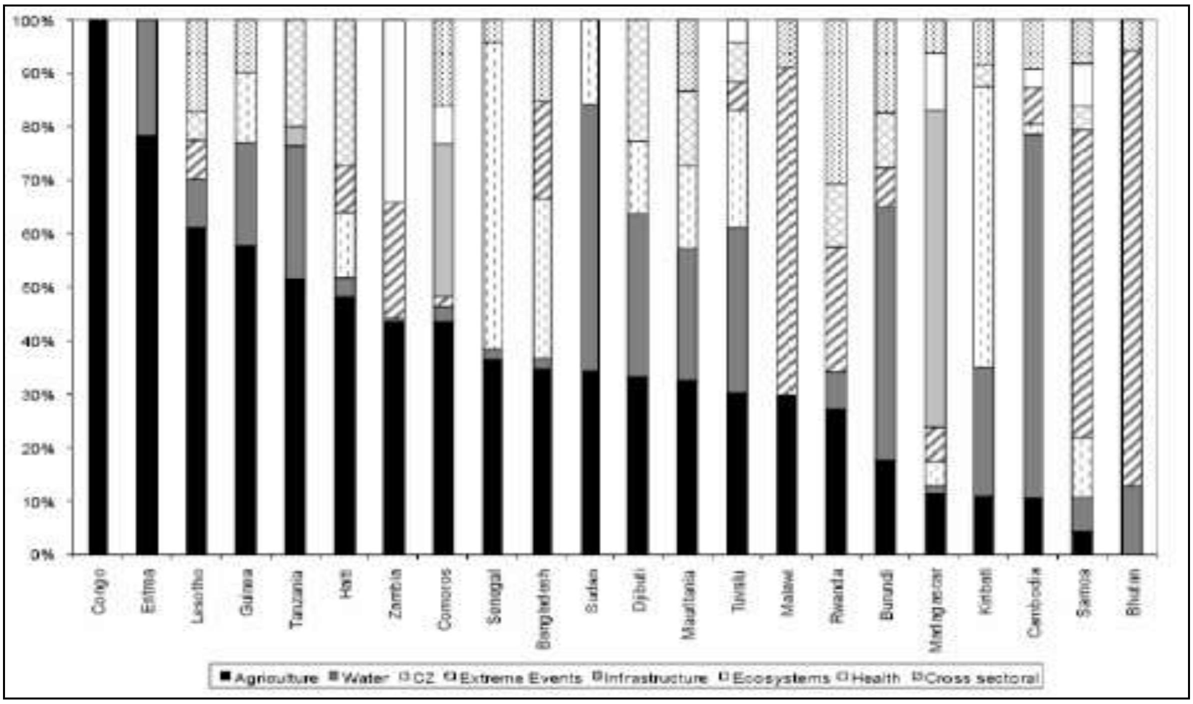


Table 26: Types of Interventions Identified in the NAPA process (food security sector) (Source:http://unfccc.int/files/cooperation_support/least_developed_countries_portal/napa_project_database/application/pdf/napa_index_by_sector.pdf).

Intervention	Country
Change in production/land-use practices: sustainable management, integrated production, zero grazing	Zambia, Yemen, Sudan, Sierra Leone, Sao Tome Principe, Mauritania, Maldives, Malawi, Liberia, Lesotho Lao PDR, Gambia, Ethiopia, Eritrea, Djibouti, Chad, Cambodia, Burundi, Bangladesh
Livelihood and agriculture diversification: access to services for agriculture and rural development (ARD), building infrastructure and capacity for ARD, agriculture extension services	Zambia, Sao Tome Principe, Niger, Nepal, Mauritania, Mali, Lesotho, Lao PDR, Haiti, Kiribati, Guinea Bissau, Guinea, Gambia, Cape Verde
Agricultural intensification	Madagascar, Guinea
Research and development of climate-resistant varieties	Yemen, Tuvalu, Tanzania, Niger, Mauritania, Mali, Democratic Republic of Congo, Comoros, Central African Republic, Burundi, Bangladesh
Developing climate-resistant irrigation systems	Yemen, Togo, Sierra Leone, Niger, Guinea, Eritrea, Burkina Faso
Improving quality of data and linking management practices to climate information	Togo, Sierra Leone, Sao Tome Principe,
Creating food banks	Niger, Chad

Climate-smart agriculture discourses
A discourse around 'climate-smart agriculture' is one that has emerged recently (e.g., OECD 2010). This discourse aims at facilitating mitigation of agricultural systems' contributions to climate change, as well as adaptation to its impacts. It is based on the premise that agriculture must undergo a paradigm shift away from 'business as usual' models in order to be resilient to climate change and be able to feed a growing population. 'For agriculture, this means: ensuring that enough food is provided for an increasing global population while reducing the carbon intensity of the agricultural sector; sustainably managing scarce natural resources – especially land, water and biodiversity – and reducing adverse environmental impacts; and enhancing the provision of agriculture-related environmental benefits such as carbon sequestration, flood and drought control, biodiversity and other ecosystem services' (OECD 2010).

The types of action that are being put on the table by both discourses are outlined in Table 27. These have been broadly clustered into: technology-based interventions; market-based interventions; and institutional/policy-based interventions.

Table 27: Actions supported by climate-resilient and climate-smart agricultural discourses.

Interventions	Actions
Technology-based interventions	Drought-/flood-resistant crop varieties; energy efficient agricultural technology; adoption of information and communication technology (ICT) to support flow and access to climate information;
Market-based-interventions	Water pricing; subsidies; climate insurance schemes
Policy/institutional-based interventions	Adoption of climate-resilient social protection polices; Promotion of farmer schools for innovation and out-scaling of climate-resilient agricultural practices; Capacity building of agricultural extension services to support climate-resilient agricultural practices; capacity building of public, private and civic institutions to support climate-resilient agriculture planning.

6.3 Actors driving global policy processes around climate change and agriculture

There is an increase in the number of actors engaged with climate change and agriculture at the global level. Given that global policy responses to climate change to date have largely been driven by the UNFCCC process, this subsection makes a distinction between actors within and outside the UNFCCC process.

Actors in the UNFCCC process: to date, policy responses aimed at addressing CC have very much been driven by the United Nations Framework Convention on Climate Change (UNFCCC). Within the UNFCCC process, policy-relevant decisions are taken by the Conference of Parties (CoP) and its subsidiary bodies – the Subsidiary Body on Implementation (SBI) and the Subsidiary Body on Scientific and Technological Advice (SBSTA). Box 4 provides an overview of the adaptation negotiations under the UNFCCC, explaining the state of play around the development of global policies for responding to climate change.

Box 4: Adaptation in the UNFCCC process.

The negotiation process
Adaptation negotiations are taking place under the United Nations Framework Convention on Climate Change (UNFCCC). Specifically, adaptation is discussed under the Ad Hoc Working Group on Long Term Cooperative Action (AWG-LCA), the Subsidiary Body for Implementation (SBI) and the Subsidiary Body for Scientific and Technological Advice (SBSTA).

- **SBI** – in relation to adaptation, the SBI is reviewing progress under Article 4 of the Convention with a specific focus on paragraphs 8 and 9 and Decision 1/CP. 10. These include issues related to assessing the adverse effects of CC on developing countries; assessing the impact of the implementation of response measures; and assessing how best to support concrete adaptation measures. Also relevant to adaptation, the SBI focuses on the financial mechanism for the UNFCCC, including the Least Developed Countries Fund and the GEF review.
- **SBSTA** – the SBSTA is reviewing the Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change (NWP). The NWP is a 5-year programme, which is going into its second phase (focusing on implementation). The SBSTA is discussing in particular: what aspects and learning from the first phase should be taken up by the SBI and what the role of the NWP should be in the future (i.e., how should the NWP inform Parties on adaptation related issues?).
- **AWG-LCA** – the AWG-LCA is an ad hoc body under the Convention which has been tasked with presenting an outcome on 'long-term cooperative action' that will enable the full, effective and sustained implementation of the Convention beyond 2012.

The state of the negotiations post-Cancun
The Cancun Climate Talks resulted in a number of agreements aimed at addressing long-term climate change. Agreements related to four of the five pillars of the Bali Action Plan include:

1. **Adaptation**: the Cancun Agreements established an **Adaptation Framework** and an **Adaptation Committee** to promote the implementation of stronger action on adaptation by providing technical support and guidance to countries, strengthening knowledge-sharing, and promoting synergy between a range of stakeholders. The Adaptation Framework calls for a greater focus on programmatic adaptation planning that is country driven, gender sensitive, and guided by scientific and traditional knowledge (amongst other aspects). The Framework also establishes a work programme to identify approaches to address loss and damage.
2. **Mitigation**: under the Cancun Agreements, developing countries committed to implementing Nationally Appropriate Mitigation Actions (**NAMAs**). The Agreements encourage developing countries to develop low carbon development strategies (LCDS) that articulate their NAMA priorities. Actions under **Sectoral Measures**, which included sections relevant to agriculture, were removed due to blockages in other areas.
3. **Technology Transfer**: the Cancun Agreements establish a **Technology Mechanism** with **a Technology Executive Committee** and a **Climate Technology Centre and Network**. Priority areas of support include: development and deployment of endogenous capacity and technology; deployment and diffusion of environmentally-sound technology; strengthening national systems of innovation and technology innovation centres; development and implementation of national technology plans for mitigation and adaptation; and other areas. The Climate Technology Centre will facilitate a network which, amongst other things, will promote North-South, South-South and triangular partnerships for cooperative R&D.
4. **Finance**: the Cancun Agreements establish the **Green Climate Fund**. The Agreements also call for balanced allocation of mitigation and adaptation funds in fast track financing and highlight that a number of sources will be required to generate the required scale of resources (public, private, bilateral, multilateral and alternative).

Where is agriculture in the negotiations?

- Agriculture has been identified as one of the most vulnerable sectors to CC. Agriculture-related projects dominate the priority projects identified under the NAPA process.
- The negotiations themselves have not gone into details related to adaptation in various sectors. However, there have been proposals to establish a work programme on agriculture under the SBSTA.
- Priority focus areas for agriculture and CC under the negotiations include: development of a land use, land-use change and forestry (LULUCF) inventory of emissions and rules that explicitly include agriculture; support the development of REDD+ and increase understanding on the role of agriculture as a driver of deforestation and the possibility of moving to REDD++; work to ensure coherence between NAMAs and NAPAs so as to ensure agriculture can contribute to food security and secured livelihoods, while simultaneously building resilience to climate change, reducing GHG emissions, and sequestering carbon; and enhance understanding on how market and other mechanisms can be used to reduce emissions from agriculture and what impact this would have on smallholder farmers (GDPRD 2010).

6.3.1 Avenues for driving global policy processes around climate change and agriculture

A number of avenues have been used by the actors above to articulate global policy discourses around climate change and agriculture. These avenues include policy frameworks; research initiatives; programmes focused on supporting learning and decision making around CC and agriculture; and climate funds.

Policy frameworks

In terms of adaptation under the UNFCCC process, NAPAs provide the most concrete avenue for adaptation planning for least developed countries to identify and implement their urgent and immediate adaptation needs currently. Based on the outcomes of the Cancun Climate Talks, countries have also been encouraged to prepare national adaptation plans to identify mid- and long-term adaptation priorities, and prepare low carbon development strategies to identify nationally-appropriate mitigation avenues. All these policy frameworks – national adaptation programmes of action (NAPAs); national adaptation plans (NAPs); and low carbon development strategies (LCDS) – provide avenues to articulate climate-resilient development pathways. And as highlighted above, a review of NAPA priorities indicates that climate-resilient interventions in the agricultural sector figure amongst the most prioritised action areas. Outside the UNFCCC process, tools like the Policy Coherence for Development (PCD) adopted by the European Union are used.

Research initiatives

A number of global, regional and national research initiatives focused on agriculture and climate change have been set up to support policy and practice aimed at delivering climate-resilient development. At the global level, the Consultative Group on International Agricultural Research (CGIAR)-led Climate Change Agriculture and Food Security (CCAFS) programme is an example of a research initiative aimed at supporting climate-resilient agricultural policy and practice. In India, for example, the programme is supporting climate risk management at farmer scale by promoting participatory action research with farmers around innovative climate-resilient agricultural practices. The programme also aims at supporting out-scaling of successful initiatives by establishing and working with local-level institutions like self-help groups and institutions for decentralised governance (personal communication with Pramod Aggarwal, 2011).

Programmes focused on supporting learning and decision making around climate change and agriculture

A number of climate change programmes have been set up at the global level to support learning and decision making around climate change. Some of these are likely to focus specifically on climate change and agriculture, whilst others have a broader focus. For instance, under the UNFCCC the Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change (NWP) and the Buenos Aires Programme of Work on Adaptation and Response Measures have been set up to support adaptation decision making and implementation. The NWP facilitates exchange of information and practical experience amongst Parties on issues relating to scientific, technical and socioeconomic aspects of CC impacts and on issues concerning vulnerability and adaptation to CC. The Buenos Aires programme aims at supporting the implementation of concrete adaptation programmes. A specific work programme on agriculture and climate change is likely to be set up under the SBSTA.

Climate funds

A number of climate funds, within and outside the UNFCCC process, support global policy processes for climate-resilient development. In terms of allocation of funding, there is a greater focus on mitigation as compared to adaptation and other priorities. For instance, 78.7 per cent of the current approved funding under the climate funds is allocated to mitigation and 13.9 per cent is allocated to adaptation. None of the funds has a specific focus on agriculture *per se* (other than funds that focus on reducing emissions from deforestation and degradation – REDD). For instance, of the approved funding, most of the funds allocated for mitigation actions focus on energy efficiency and supporting renewable energy development. In terms of adaptation, a number of projects focus on supporting climate-resilient agricultural practices (www.climatefundsupdate.org). Within the UNFCCC process there are four climate funds. These include:

1. The Least Developed Countries Fund (LDCF);
2. The Special Climate Change Fund (SCCF);
3. The Kyoto Protocol Adaptation Fund (AF); and
4. The Green Climate Fund (GCF).

The **LDCF** supports the preparation and implementation of national adaptation programmes of action (NAPAs). NAPAs focus on enhancing adaptive capacity to climate variability and provide a process for LDCs to identify priority activities that respond to their urgent and immediate needs with regard to adaptation to climate change.

The **SCCF** focuses on climate-resilient development. Identified activities should be country-driven, cost-effective and integrated into national poverty reduction strategies.

The **KPAF** will finance concrete adaptation projects and programmes in developing countries that are particularly vulnerable to the impacts of climate change.

The **GCF** has been established as an outcome of the Cancun Climate Talks. Its institutional architecture and functions are currently under design. Long-term multilateral funding for adaptation is likely to flow through the GCF.

Existing adaptation funds under the LDCF and the SCCF have been disbursed using project-based mechanisms; however following the recent review, disbursement channels are likely to include-programme based mechanisms. The AF is currently the only fund that will allow 'direct access' to developing country Parties and implementing and executing agencies (Brown *et al.* 2010). The fund also refers specifically to vulnerable communities and community-based adaptation programmes as a modality to access funding. Though communities cannot directly access funds, the AF is the only mechanism that allows developing country governments to work with organisations that have particular expertise in targeting the most vulnerable communities (Harmeling *et al.* 2008).

Outside the UNFCCC process

A number of new climate change funds outside the UNFCCC process have also been set up. These have an adaptation and a mitigation component and are also depicted in Table 28, below.

Table 28: Multilateral and bilateral funds for adaptation and mitigation as of June 2011 (Source: www.climatefundsupdate.org).

Fund	Type	Administered by	Area of focus	Date operational
Adaptation Fund	Multilateral	Adaptation Fund Board	Adaptation	2009
Amazon Fund (Fundo Amazônia)	Multilateral	Brazilian Development Bank (BNDES)	Mitigation - REDD	2009
Clean Technology Fund	Multilateral	The World Bank	Mitigation - general	2008
Congo Basin Forest Fund	Multilateral	African Development Bank	Mitigation - REDD	2008
Forest Carbon Partnership Facility	Multilateral	The World Bank	Mitigation - REDD	2008
Forest Investment Program	Multilateral	The World Bank	Mitigation - REDD	2009
GEF Trust Fund - Climate Change focal area (GEF 4)	Multilateral	The Global Environment Facility (GEF)	Adaptation, mitigation - general	2006
GEF Trust Fund - Climate Change focal area (GEF 5)	Multilateral	The Global Environment Facility (GEF)	Adaptation, mitigation - general	2010
Global Climate Change Alliance	Multilateral	The European Commission	Adaptation, mitigation - general, mitigation - REDD	2008
Global Energy Efficiency and Renewable Energy Fund	Multilateral	The European Commission	Mitigation - general	2008
Hatoyama Initiative - private sources	Bilateral	Government of Japan	Adaptation, mitigation - general, mitigation - REDD	2008
Hatoyama Initiative - public sources	Bilateral	Government of Japan	Adaptation, mitigation - general, mitigation - REDD	2008
Indonesia Climate Change Trust Fund	Multilateral	Indonesia's National Development Planning Agency	Adaptation, mitigation - general, mitigation - REDD	2010
International Climate Fund	Bilateral	Government of the United Kingdom	Adaptation, mitigation - general, mitigation - REDD	2008
International Climate Initiative	Bilateral	Government of Germany	Adaptation, mitigation - general, mitigation - REDD	2008
International Forest Carbon Initiative	Bilateral	Government of Australia	Mitigation - REDD	2007
Least Developed Countries Fund	Multilateral	The Global Environment Facility (GEF)	Adaptation	2002
MDG Achievement Fund – Environment and Climate Change thematic window	Multilateral	UNDP	Adaptation, mitigation - general	2007
Pilot Program for Climate Resilience	Multilateral	The World Bank	Adaptation	2008
Scaling-Up Renewable Energy Program for Low Income Countries	Multilateral	The World Bank	Mitigation - general	2009
Special Climate Change Fund	Multilateral	The Global Environment Facility (GEF)	Adaptation, mitigation - general	2002
Strategic Climate Fund	Multilateral	The World Bank	Adaptation, mitigation - general, mitigation - REDD	2008
Strategic Priority on Adaptation	Multilateral	The Global Environment Facility (GEF)	Adaptation	2004
UN-REDD Programme	Multilateral	UNDP	Mitigation - REDD	2008

6.4 Platforms, processes and players outside the UNFCCC framework

Global donor platform: Agriculture and Rural Development Day

Proposals on how and why to include agriculture in the post-2012 climate regime have been made clear, e.g., by the Global Donor Platform for Rural Development (GDRPD 2009). For the second year running, 19 leading organisations from the UN, governments, development agencies, civil society, farmer groups, research groups, private sector and the media convened the Agriculture and Rural Development Day (ARDD) on the sidelines of the UNFCCC Conference of Parties COP16 in 2010 (see: www.agricultureday.org). The output of the session highlights the strong link between climate change and food security, with the resulting statement recognising the key issues characterising climate change and food security, as well as identifying several actions. The ARDD proposed the following urgent actions:

- Allocate fast-track financing to support agriculture adaptation and mitigation activities.
- Action on food security, nutrition and hunger must be explicitly included in any post-2012 agreements, especially within long-term cooperative actions (AWG-LCA text).
- A decision to set up an agricultural work programme under the Subsidiary Body for Scientific and Technological Advice (SBSTA) is the first step in this direction.
- REDD+ should explicitly recognise the links between agriculture and forestry, and if properly designed it should promote sustainable agriculture intensification and reduce deforestation, while improving rural livelihoods.
- Recognise the synergies and opportunities for adaptation, and mitigation co-benefits.
- New or revised Clean Development Mechanism (CDM) and other mechanisms need to include agriculture and other land-use changes.

Global conference on agriculture, food security and climate change

From 31 October to 5 November 2010, the Government of The Netherlands, in close cooperation with the governments of Ethiopia, Mexico, New Zealand, Norway, Vietnam, the World Bank and the FAO, organised the 2010 conference on Agriculture, Food Security and Climate Change in The Hague. The conference enabled governments, international organisations, the private sector, NGOs, philanthropic foundations, local community producers and the scientific community to jointly develop a roadmap with concrete actions linking agriculture-related investments, policies and measures to the transition to lower carbon-emitting climate-resilient growth (see: http://www.afcconference.com/final-roadmap-for-action). The conference was held in the context of the discourse that proposes that agriculture can be the solution to many of the world problems.

The objectives of the conference were to identify concrete actions linking agriculture-related investments, policies, and measures with the transition to climate-smart growth. It developed a roadmap with several activities by different actors, but specifically the conference:

- Identified what needs to happen for agriculture and related land-use, forest and water management to deliver on increased productivity, reduced emissions, increased sequestration, environmental sustainability, better livelihoods, and food security.
- Showcased issues and shared knowledge on replicable good practices in climate-resilient, low-emissions agriculture; livestock; fisheries; forestry; and watersheds management and demonstrate the potential for scaling up in a sustainable manner.
- Used innovative approaches to bring together private and public sector finance for investments in climate-smart agricultural systems.

It was noted that there are a number of related processes and assessments in the realm of agriculture, food security and climate change, such as the Convention on Biological Diversity (CBD), United Nations Convention to Combat Desertification (UNCCD), UNFCCC, United Nations Forum on Forests (UNFF) and International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD).

Global research institutions: Climate Change, Agriculture and Food Security (CCAFS)
CCAFS is a 10-year research initiative launched by the Consultative Group on International Agricultural Research (CGIAR) and the Earth System Science Partnership (ESSP), seeking to overcome the threats to agriculture and food security in a changing climate by exploring new ways of helping vulnerable rural communities adjust to global changes in climate. CCAFS is one of the major initiatives that bring together climate change and agricultural issues in a practical way, and it represents a big step by one of the largest agricultural players (CGIAR) to get climate change and agriculture together. Being a research programme, CCAFS is an opportunity to inform how climate change could be addressed by most players in the agricultural sector, including research, practice and policy making.

The CCAFS research themes are adaptation to progressive climate change; managing climate risk; and pro-poor mitigation and integration for decision making. In addition to research, CCAFS also supports capacity enhancement among different stakeholder groups to overcome the additional threats posed by a changing climate to achieving food security, enhancing livelihoods, and improving environmental management. CCAFS's work initially focused on East Africa, West Africa and the Indo-Gangetic Plains, involving 36 sites that represent areas that are becoming both drier and wetter, and are focal locations that will generate results that can be applied and adapted to other regions worldwide.

In 2011, CCAFS set up the Commission on Sustainable Agriculture and Climate Change, which will identify what policy changes and actions are needed to help the world achieve sustainable agriculture in the face of climate change. The commission will use existing studies to arrive at its recommendations, becoming a significant source of guidance on how agriculture could be addressed by climate change decision makers, especially in the area of sustainable agriculture.

European Initiative on Agriculture and Rural Development (EIARD)
The European Initiative on Agricultural Research for Development (EIARD) is a permanent informal agricultural research for development (ARD) policy coordination platform between the European Commission, member states of the European Union, Switzerland and Norway (EIARD 2010). It facilitates the coordination of European policy and support for ARD. Its main areas of activity are (see: http://www.eiard.org/about/activities/):

- Coordination of European ARD policies in pursuit of the MDGs.
- Coordination of European investments in CGIAR.
- Coordination of European investments in strengthening ARD organisations at global, continental and sub-continental levels, especially in Africa.
- Coordination of European investments in ARD and investments in rural development in the pursuit of the MDGs.

EIARD members include the 27 member states of the European Union, plus Norway, Switzerland and the European Commission – represented by the directorates general for Research (DG RTD), Development (DG DEV), and Europe-Aid Office for Cooperation (DG AIDCO). Each member has a national EIARD network consisting of ARD policymakers from the relevant ministries and government departments and their advisers.

EIARD has recently recognised climate change as an important issue in its activities, demonstrated by its recognition in its 2009/2010 annual report. In this report, EIARD identifies CC as a priority issue and its objective in CC engagement is to ensure that the dimension of agricultural research for development is acknowledged as a key factor to be considered when addressing the challenges of CC and the MDGs (see: http://www.eiard.org/media/uploads/documents/annual_reports/draft_eiard_2010_activity_report_v_finale.pdf).

Recently, Anderson *et al*. (2010) did a review on the impacts of climate change on food security in Africa, which is utilised by EIARD as a key document (see: http://www.eiard.org/media/uploads/documents/thematic_studies/final_report_iied_16_april_2010.pdf). The study assessed different components of the context for EIARD member support of ARD for food security and climate change in Africa including: concerns on food security, impacts of climate change across Africa, how food security is and will be affected by climate change, public and private sector investments in African agricultural research and development, the trade-offs and relationships between adaptation and mitigation dimensions of climate change and food security in Africa; and the joint donor guidelines for agriculture and rural development, particularly alignment and harmonisation.

Global private sector

Seed, biotechnology and agrochemical companies are critical players in the area of climate change and agriculture. For example, BASF, Monsanto, Bayer and others have been taking steps to develop and deliver crop varieties that withstand climate-related stresses such as drought, heat, cold, floods and salinity (see: http://politicook.net/2008/06/12/monsanto-to-re-brand-as-climate-change-savior/). Bayer CropScience has initiated a number of projects to make plants more stress-resistant and achieve a significant increase in agricultural productivity, as well as undertaking research into ways to make greater use of plants as fuels while ensuring that the cultivation of such plants does not conflict with the production of food (see: http://www.presse.bayercropscience.com/bcsweb/cropprotection.nsf/id/EN_Challenge_Climate_Change).

The influence of private companies on global agriculture is evidenced by the fact that the top ten seed companies control 57 per cent of the global seed market (see: http://politicook.net/2008/06/12/monsanto-to-re-brand-as-climate-change-savior), and appropriate seed varieties are often noted as important for adapting to climate change. The Bill and Melinda Gates Foundation and the Howard G. Buffet Foundation (both private) are also significant players in agriculture. They currently fund a US$47 million project, 'Water Efficient Maize for Africa' (WEMA), to develop biotech and conventional maize seeds for sub-Saharan Africa, working with Monsanto and BASF (see: http://www.monsanto.com/ourcommitments/Pages/water-efficient-maize-for-africa.aspx).

If such initiatives enable agriculture to adapt to climate change, they represent a significant flow of funding involving the private sector. Biotech, patents, ethical and business practices, however, are issues around which private companies have been criticised, especially as they pertain to their dealings with poor farmers in developing countries. Environmental considerations have also been raised in the way global private companies operate in developing countries. However, their involvement and the extent of their influence have significant implications on the extent and nature the role of global private players on adaptation that delivers food security in its various elements (production, access, utilisation etc.). A key question is the share of the adaptation cost that can be borne by the private sector to deliver global food requirements in a way that is fair and environmentally sustainable.

Fair trade initiatives that link local farmers with global businesses and consumers have the potential to support climate-resilient agriculture in developing countries, especially in export-focussed agricultural systems. In the Rwanda coffee system, and in the Malawi case study area, where smallholder farmers are contracted by the adjacent sugar company to grow sugar for its mill, fair trade initiatives that already exist could also support adaptation. These initiatives have the potential to distribute the costs of adaptation over a wider range of sources.

While we have not looked into the role of the global private sector in agricultural mitigation, it is clear that this is an important area for consideration.

Emerging sources of development finance

In addition to these private sector opportunities, there are also emerging, non-traditional sources of development funds for developing countries (such as partnerships with China, Brazil and India) that could be used to support climate change adaptation. Engaging them will shape both global climate change policy and the delivery of adaptation in developing countries. Currently, engagement with these large economies in the climate change debate focuses on mitigation and less on adaptation.

6.5 Implications for a coordinated global response

It is evident that several global processes are emerging to address climate change and agriculture, and all are coming from different starting points. With respect to the three categories considered here (climate change framework, agricultural development, private sector), the coordination required among them is in the areas of technical and technological expertise, policy, coordination and financing.

What are the opportunities for them to coordinate and maximise on their respective strengths? It is clear, for example, that global donor support for agricultural research and development has been declining. For instance, donor countries reduced official aid to agriculture from 16.8 per cent of all official development spending in 1979, to just 3.4 per cent in 2004 (Anderson *et al.* (2010). It is also clear that adaptation funding from UNFCCC sources is far below requirements, and there is no amount earmarked for agricultural adaptation. Private sector investment, on the other hand, is increasing. For example, €3.5 billion will be invested in research and infrastructure development for biotechnology and seed development by Bayer CropScience over the next ten years, to respond globally to new challenges in terms of growing conditions (Anderson *et al.* 2010). Global agricultural research organisations – such as CGAIR research centres – have vast experience undertaking research that generates practical solutions in developing countries, thus they are well placed to translate global adaptation priorities into practical delivery, at least from a research perspective. They also have experience working with developing country governments and NGOs in their research activities. A coordinated approach that harnesses and prioritises use of resources and addresses the concerns raised about the private sector could lead to effective global policy signals for developing countries.

The global policy response, especially in financing, should align with existing developing country institutional and implementation arrangements in order to be effective (Cabral 2010) and to avoid developing countries changing their policies and institutions each time there is a new global initiative. This is consistent with the approach of this study, which looks at the existing development and livelihood pathways in developing countries and their communities as the starting point for planning and costing adaptation. Working with existing relevant institutional frameworks (with minor tweaks) would minimise the cost of adaptation associated with creating new institutions, except where the need is clear.

6.6 Conclusion

Policymaking, funding and mobilisation of technology and technical expertise are some of the key functions that the global policy platforms and processes must coordinate, and these must be informed by the realities on the ground. The adaptation actions that are promoted by the dominant global discourses around climate change and agriculture need to have been identified via bottom-up processes that reflect real-life development pathways. These need to include resilience, market-based instruments, and policy/institutions/technology-based interventions. The channels that link the global players to the national levels also need to be harmonised so that the local realities are uniformly fed into global planning processes. For example, NAPAs should not only be for the consumption of UNFCCC platforms, but should be targeted at the private sector and agricultural development donors as well, since they spell out local adaptation needs. Similarly, UNFCCC processes should also draw on existing local agricultural research knowledge in planning adaptation and prioritising funding.

7. Key messages and policy implications

7.1 Introduction

Avoiding dangerous and costly climate change requires an ambitious global policy that translates into action at all levels of society and in all sectors. Adaptation is an important part of the solution, together with mitigation – especially for developing countries that are set to lose on food provision, livelihoods, and their economies. Because global food security is under threat from an increasing global population, agricultural adaptation is one of the key issues that needs to be integrated into a climate change policy, in a way that harmonises the efforts of various players at all levels. As this study has shown, actors, levels, pathways and dimensions of adaptation – are important aspects in adaptation planning. A consideration of these and other factors consequently influences the nature and outcomes of adaptation planning and economics.

Actors: government, private sector, local communities (collectively and as households) and NGOs all need to be involved at their different levels, with any plans needing to reflect how different actors will be involved in adaptation.

Levels: we have analysed the various levels of adaptation planning at which investment needs to be made. The global level needs effective coordination among players in the climate change policymaking process, the agricultural and rural development community (including research organisations and donors), and the private sector, among others. In developing countries, the national, district and local levels are all targets of adaptation investment that need to be adequately coordinated and funded. Indeed, the climate change solution will emerge from the actions at all levels, not just one. This should be a key component of a new global climate policy.

Pathways and dimensions: adaptation that delivers food security needs to target the different aspects of food security from production to utilisation, including market value chains and pricing signals. Additionally, adaptation is part of a development pathway that is likely to be affected by climate change. Actors therefore build on their current efforts to address development deficits and their pursuits of development goals, asking for climate change to be reflected in these development policies. Isolated adaptation strategies are not sustainable on their own, or could duplicate existing efforts – leading to inefficiencies in resources utilisation.

Consequently, the costing of agricultural adaptation is not a straightforward exercise that will arrive at the same answer each time a methodology is applied on a sample of countries or communities. We have demonstrated that developing country agriculture is heterogeneous, with variable systems that have different objectives – such as subsistence or cash – and their combinations. To plan effectively for adaptation these require reliable, high-resolution climate change information that gives actors the confidence to invest in long-term adaptation (as opposed to short-term responses that are only informed by historical experiences). But this is not immediately available and local planners, for now, will depend on generalised, low-resolution climate information and their local experiences to plan adaptation. Indeed, both top-down and bottom-up costing studies are subject to an infinite number of variables such that they need to be designed to address specific requirements in addition to the general objectives of just costing adaptation. Answers from general studies are useful to guide fundraising at global levels, but they are expected to be highly variable, if not speculative.

7.2 Key messages for decision makers

Our analyses, over a relatively short space of time, conclude with messages for decision makers in four key areas of agricultural adaptation:

1. Adaptation decision making. How can we choose effective adaptation pathways across levels and actors?
2. Agricultural adaptation. What do adaptation pathways for the agriculture sector look like?
3. Costing findings. How much is adaptation in agriculture going to cost?
4. Institutional coordination. How can institutional coordination be enhanced to support this process

7.2.1 Adaptation decision making

A. **There are an infinite number of possible adaptation futures and pathways. A 'Signatures Approach' reduces this to a more manageable – but still very large – sub-set of possible actions and plans.**

Development and adaptation should not be seen as a single path along which systems and countries move at variable speeds. There are a theoretically infinite number of possible adaptation futures and pathways. Actions by actors at all levels change the pathway taken. Actions to build capacity today by assigning resources to a given purpose open up future possibilities but also close off possibilities due to competing demands for those resources; adaptation action has an opportunity cost. Furthermore climate change alters the potential future options, usually, but not always, by closing off potential future opportunities. Failure of a system to sufficiently adapt to variability in the environment in which it operates will result in that system contracting in scale and potentially collapsing. In this way, economic systems can be seen as behaving very much like ecosystems. If the system fails to adapt sufficiently to its environment it dies out and competing systems take its place. This should not be considered a 'neutral' occurrence. Certain systems and potential states of the world are more desirable than others. Adaptation actions both need to allow the system to survive in the short term but also to become the basis of further adaptation and development ability and action in the future.

B. **At least in the short term, countries are capable of developing adaptation plans with limited access to complex (and mostly unavailable) scientific climate change projections**. At a community level, sophisticated climate change information becomes less relevant for decision making, as adaptation is very much based on existing conditions, especially where climate variability is already a factor. However, climate change information specific to each country and its local regions needs to be developed beyond what is currently available, and used to inform forward planning and to avoid maladaptation.

Current climate change information is generally weak in all countries, leading to actions that only respond to observed climate variability and not climate change. Whilst building experiences from coping with variability is valuable, a weak climate change information base may lock countries and communities into short-term responses that do not cater for more intense climatic changes that will evolve in the future. Short-term responses may also be maladaptive, or may be costly as these need to be repeated again and again without actually cushioning countries from increasing climatic changes. Community surveys in our case studies show significant numbers of households mentioning coping strategies as adaptation strategies. At the national level, most development plans and visions do not take into account climate change information. Being long term in nature, pertaining to 10-, 20- or even 30-year timeframes, their realisation is likely to be affected by climate change.

This study employed a combination of local climate change knowledge and downscaled models in engaging stakeholders. These were only useful in as far as generally raising awareness about climate change. Detailed adaptation actions seemed not to be based on specific projections of climate, but rather on the need to minimise the impacts of droughts, floods or salinity. Overall, it seems countries or communities could come up with adaptation plans without having to rely overly on climate science.

C. **National-level institutions may have very different perceptions as to the nature of the climate change problem and the best forms of adaptation. These need to be harmonised.**

National-level institutions, including government ministries and research institutions, are staffed by individuals who have much better than average educations and who are therefore no longer engaged with subsistence agriculture. In some instances they may (often unconsciously) hold elitist attitudes with respect to farmers. This can manifest itself in not considering the views, understanding, and (crucially) knowledge of farmers as important to climate change decisions. Illiteracy among farmers is sometimes used as justification for this point of view. Alongside this perspective comes a tendency to want to centrally organise agriculture, and lack of action on climate change adaptation is blamed on farmers not following the policies that thus advocated. Sometimes this view is reinforced by the hierarchical structure of society and government.

Such views are often held through ignorance of the nature of the costs, benefits and risks faced by individual farmers and misperception of the incentives that farmers are presented with. In this context, extension services can be perceived by institutional actors as a way of 're-educating' farmers towards the policy perspective of the institution. Ideally, extension services should facilitate the relay of information gathered at the local level through to policy institutions; the two-way information flow between the national and local levels is an important part of adaptation policy coordination.

Adaptation measures that do not have local support and 'buy-in' are likely to be more expensive and less effective. More has to be spent on communication between institutional and local-level actors, and greater incentives provided to encourage local actors to participate. In the first instance, pursuing adaptation actions where there is agreement between local-level and national-level actors may be most effective. One way this could be achieved is by persuading institutional actors to take the needs, aspirations, knowledge and understanding of farmers and other local-level actors seriously.

7.2.2 Agricultural adaptation

A. **Research, capacity building and extension are the common pillars for effective adaptation across all agricultural systems.**

The specific adaptation actions vary widely across the different agricultural systems in this study, ranging from land-use planning and migration in the livestock sector of Tanzania, through upgrading coffee washing stations in Rwanda to developing salinity-resistant rice varieties in Bangladesh. A common feature among all the case studies is the need to undertake more research that informs future adaptation. Institutional and technical capacity building is of limited use if the products of their work fail to have an impact on local-level farmers. The requirement to support the adaptation actions of farmers through extension services is also common among most of our case studies. These functions are normally carried out at national level by government. It is our recommendation that at the minimum, these be established and developed further to build a strong national adaptation base that enables autonomous responses.

B. **The adaptation actions favoured by both institutions and farmers tend to be extension and scaling up of existing methods for coping with climate variability.**

All agricultural systems face a degree of variability in the climatic and other environmental systems on which they depend, and have developed methods for coping with this variability. Often these methods are forms of diversification and risk spreading, either through storing reserves, having access to alternative resources, or sharing risks within the community. Similarly, institutions have established research programmes, methods and ideologies as to how development should be pursued. When asked for their perceptions of the most urgent or preferable adaptation actions to cope with future variability caused by climate change, previously used coping strategies were found to 'anchor' their responses. Furthermore, in agricultural systems the production of certain crops may have deep cultural rooting.

This tendency may prove to be a two-edged sword. On the positive side, there is often considerable opportunity to upgrade existing strategies to allow them to cope with increased climate variability. There has already been considerable 'learning by doing', which has built up knowledge of these potential adaptation techniques making them more effective and potentially cheaper in the short term. Such actions may also be perceived as only an incremental change in existing practice, supporting greater 'buy-in' by effective actors.

However, as the extent of climate change increases, successful adaptation may not only require a change in the scale of actions but also a change in the type of action. Past certain thresholds, existing adaptation techniques are unable to cope with the new climate and entirely new techniques are required. If such a qualitative shift in adaptation is required, 'anchoring' to past experience slows the adoption of new technologies due to cultural inertia.

C. **The scope of agricultural adaptation: production and non-production aspects need to be adapted to climate change.**

Agriculture in most developing countries is important for both the production of food that people eat and as a source of livelihoods (in sub-Saharan Africa, for example, two-thirds of the working population derive their livelihood from agriculture). Changing climates will have adverse effects on food production, food distribution, infrastructure, land availability for agriculture, livelihood assets and opportunities in rural and urban areas. Adapting food systems to both enhance food security for the poor and to sustain livelihoods in the wake of climate change will require attention to more than just agricultural production. Food security can only be ensured and enhanced with a range of interventions across activities and agricultural systems – ranging from production to distribution and allocation – informed by an understanding of how the systems function and are affected by climate change. Adaptation planning needs to reflect on Pretty *et al.*'s (2010) 'Top 100 questions of importance to the future of global agriculture', which involve considering the natural resource inputs into agriculture, agronomic practices, and agricultural development, as well as markets and consumption. This essentially requires looking at how climate change affects all the stages of the agricultural production system, rather than just a single stage. The issues to take into account are:

- Climate, watersheds, water resources and aquatic ecosystems.
- Soil nutrition, erosion and use of fertilizer.
- Biodiversity, ecosystem services and conservation.
- Energy, climate change and resilience.

- Crop production systems and technologies.
- Crop genetic improvement.
- Pest and disease management.
- Livestock.
- Social, capital, gender and extension services.
- Development and livelihoods.
- Governance, economic investment, power and policymaking.
- Food supply chains.
- Prices, markets and trade.
- Consumption patterns and health (Pretty *et al*. 2010).

The extent to which these issues are incorporated into adaptation planning determines the policies and institutional arrangements that need to be put into place for agricultural development in the face of climate change. It is clear from the literature and from country-specific studies that the costing of adaptation omits such issues as ecosystem services, food supply chains, marketing and trade, whose inclusion would change the cost – and probably the effectiveness – of adaptation. Market chain adaptation has been seen to be especially critical in cash crops such as export coffee in Rwanda, where failure to adapt along the market chain significantly reduces the quality of coffee, affecting value and farm gate price, irrespective of on-farm productivity.

It is therefore recommended that adaptation investment should target both the production and non-production elements of agriculture, as the non-production elements are important for stimulating autonomous responses in the production sectors, while also providing the opportunities for private sector investment. Adaptation plans should reflect this relationship, and make appropriate funding allocations.

7.2.3 Costing findings

A. **Top-down adaptation costing approaches do not accurately reflect, and often underestimate, the cost of adaptation, but bottom-up approaches are highly sensitive to the level of detail and development variables and cannot be aggregated to arrive at realistic global estimates.** Any bottom-up cost estimate should be done to fit its specific purpose, and not all purposes generally.

Top-down methods for costing adaptation have been criticised for not adequately reflecting local realities, especially in developing countries. Bottom-up approaches, on the other hand, hold promise for more refined cost estimates. Parry *et al.* (2009) show that UNFCCC estimates on the cost of adapting to climate change are substantial under-estimates of real costs. No bottom-up studies on the costs of adaptation are comprehensive enough to provide a full picture either for a country or for a sector. Most studies focus on a specific indicator, such as child nutrition, agricultural research and extension, or capital formation, rural infrastructure etc. Pulling up all possible costs from the bottom upwards is often complicated by the multiple actions that are required to adapt the agricultural sector to uncertain future climates. Adaptation actions are difficult to separate from development variables (it is common for existing rural development activities at the local level to be labelled 'adaptation activities' while local stakeholders often term their coping strategies 'adaptation actions'). Omission or inclusion of these in costing studies result in significantly variability in adaptation estimates across different case studies. The country case studies under this project also show highly variable estimates due to the level of detail included in cost estimations. These range from US$0.3 million per year to US$283.3 million per year for the immediate term. They are context-specific, and depend a lot on the variables used in the estimations and the areas of focus prioritised by local stakeholders. Thus while bottom-up approaches are preferable as more realistic estimates of the costs of agricultural adaptation, they need to be put into specific contexts for them to be meaningful, and their aggregation to global and even national levels could be highly erroneous.

Global cost aggregates are only useful to provide an order of magnitude to direct resource mobilisation efforts, while local-level cost estimations are mostly useful for specific country and project budgeting purposes. In the same way that country costs should not be extrapolated from top-down estimates, global estimates cannot be realistically aggregated from a limited number of local cost estimates.

Fit-for-purpose cost estimations are more reliable than general estimates. For example, a project designed to undertake a specific adaptation action can estimate realistic costs within its boundaries as dictated by its goal and intended impact or results. Fit-for-purpose, bottom-up costing can also show how the costs could be distributed over time. For example, the Malawi case study shows that of the US$55 million cost of adaptation for the next five years, US$30 million could be provided by, or funded through, the private sector.

B. **Isolating and precisely estimating the 'costs of adaptation' within planning and costing is not possible.**

Attempting to estimate the costs of adaptation using a bottom-up approach requires a plan of what is to be costed. However, adaptation plans to be implemented with limited resources inevitable lead to questions of 'how much will this cost?'. This could be seen as the basis of a 'costing and planning paradox' where it is not possible to precisely plan without costs and it is not possible to cost without plans. Furthermore, both planning and costing require assumptions to be made and the results of the planning and costing analysis is highly sensitive to these assumptions.

In addition to this, many of the actions which are required for successful adaptation require investment in the capability of systems that have both development and adaptation uses. As has been previously noted, the division between adaptation and development is a false distinction in practice. In many cases it is not practically possible to break down the actual costs of an action into its development and adaptation components.

C. **A key economic consideration for agricultural adaptation is where to invest the limited adaptation funds.** Adaptation funding must be invested at national, district and local levels to achieve the best impact in the short and long terms, and be targeted at various actors who play several roles that enhance overall effectiveness.

The costs of adaptation are highly variable, depending on the agricultural system, the costing approach employed, the scope of adaptation measures, and many other variables. Production-level adaptation strategies and actions are largely influenced by signals from public policies and the economic environment. Agrawala and Fankhauser (2008) suggest two categories of agricultural adaptation strategies, these being farm level and public level. The adaptation actions and associated costs estimated by the country studies under this project fall into three main levels: national level, district level and local level. This suggests that any planning and funding of agricultural adaptation should target these three levels adequately as they are mutually supportive.

1. National-level actions include policymaking, institutional capacity building, planning, coordination of local activities, research, and extension services. These are mostly linked to specific government departments within the ministry responsible for agriculture, and are measured as additional budgetary requirements.
2. District-level actions include farmer training, provision of local infrastructure, distribution of technologies, facilitating private sector relationships with local communities, and coordinating and harmonising local players through district planning processes. The costs incurred by NGOs are either at the local or district level, often covering more than one community in a district, but often not covering all households in a district. The scale of NGO actions is highly variable.
3. Local-level adaptation actions identified are those taken directly by households either on their own or with the facilitation of NGO or government institutions. Their actions range from simply adopting technologies that they pay for to coordinated activities such as participation in village savings banks and other development projects that pool risks and/or diversify their livelihoods away from agriculture.

The distribution of costs by level is highly variable depending on the agricultural system as well as the detail put into the estimations. In Bangladesh, where the main adaptation required is to reduce the impacts of salinity, the costs are almost entirely borne at the national level, where research and promotion of saline-resistant crop varieties are the main activities. In this case, the cost to farmers of using existing and improved rice varieties is the same. Similarly, the Rwanda estimation of costs assumes that the players at each stage of the coffee value chain will respond autonomously to signals from national-level institutions and thus do not account for their costs, i.e., they are treated as private costs of adaptation. On the other hand, adapting Tanzania's livestock sector to climate change involves significant costs at the local level, with activities such as land-use planning, provision of watering points, and migration (temporary and permanent), constituting the bulk of the costs. The Malawi and Nepal case studies also include costs of local-level adaptations by households.

It is recommended that future adaptation plans and funding proposals include an analysis of the distribution of actions and costs at these levels, and put in place plans to allocate respective budgets to them. In addition to the levels, it is recommended that the respective actors for the actions and budgets also be identified, including opportunities for private sector players. Reflecting levels and actors in plans and funding proposals enables governments, donors and the private sector to target funding effectively and where it is most required. A large adaptation budget that reflects a significant input by the private sector at the local level may imply that actual donor or government funding required is small compared with the actual budget. This study did not go to this level of detail in its analysis, but was informed by the concept of stakeholder-focused cost-benefit analysis.

The deployment of adaptation funds should prioritise impact and delivery. Lessons from sector-wide approaches show that impact and delivery could be hampered by a strong focus on systems and processes, as well as lack of a suitable M&E framework.

7.2.4 Institutional coordination

A. **Clear assignment of institutional responsibility for coordinating climate change adaptation nationally will enhance effective action at all scales in developing countries.**

Most of the countries in the study have complex, and often confusing, institutional structures that are relevant for agricultural adaptation but which lack the mandate to coordinate or lead implementation. On the one hand, institutions that lead climate change processes at country level, such as the ministry responsible for the environment or the meteorological department, do not have extensive technical presence below the national level (this is the situation in almost all the case study countries). On the other hand, agricultural departments, through extension services, reach out to the lowest level by interacting daily with farmers, yet are not involved in day-to-day climate change planning and decision making. A common feature of all country policies, however, is decentralisation, which provides for local-level planning and implementation of development activities, and which brings together several institutions at the district level. Decentralised planning and implementation will thus be key to effective agricultural adaptation on the ground. Other important functions – such as agricultural research and meteorological observation – also need to strengthen their engagement with, or presence, in local-level planning and implementation processes in order adequately to inform stakeholders how local actions can take climate change into account. Agricultural adaptation requires a combination of local climate knowledge and scientific knowledge.

B. **Adaptation should be mainstreamed into existing institutions, planning processes and programmes at both national and local levels, with agricultural institutions taking the driving seat in agricultural adaptation.**

The national adaptation programmes of action (NAPAs) have been the main adaptation planning platforms in developing countries, but these have mostly focussed on immediate needs with a short timeframe. Most NAPAs are collections of projects that address specific adaptation needs. They have not been widely taken up for implementation either by the climate change institutional mechanisms in these countries or by the respective sectors which they relate to. Yet developing countries have well-developed agricultural planning and implementation institutions and policies from national to local levels. What they need is harmonisation and coordination in order to address climate change adequately. The adaptation actions identified in country studies under this project are mostly extensions of activities that fall under existing agricultural institutions and national- and local-level planning processes. In most developing countries, poverty reduction strategy papers (PRSPs) and other strategies for poverty reduction provide a point of reference for national development efforts as well as for the international development community. The harmonisation, alignment and results agenda works to enhance the impact of development assistance through improved coordination at the country level combined with strengthened country ownership of development efforts (IFAD 2006). Sector-wide approaches generally, and agricultural/rural ones in particular, lie squarely within this international development architecture. The appeals of agricultural SWAPs include (IFAD 2006) that:

- They seek to define the agriculture sector broadly in order to encompass the range of factors that affect the success of agriculture-based livelihoods – and as such they may engage other ministries that can contribute to this agenda, coordinating the inputs of various actors, including an involvement of the private sector.
- Their cross-sectoral approach means that they may more accurately be considered to be rural livelihood or rural development initiatives, and they are often constructed to be the 'rural pillars' of PRSPs.
- They are also strongly endorsed by the *Paris Declaration on Aid Effectiveness* of 2005 (OECD 2005).

These are critical for agricultural development and food security in a changing climate. Traditional agricultural departments, for example, need to coordinate closely with meteorological departments, disaster management departments, environment departments and others in order to address the likely impacts of climate change effectively.

At the local level, experiences in Nepal show that local-level adaptation plans of actions (LAPAs) are effective means for mainstreaming adaptation at the local level, while in Malawi, the district planning framework brings together all government and non-government players working in a specific district to harmonise their actions. It is at this level that local priorities are formally integrated and mainstreamed.

Regional agricultural programmes are also critical for mainstreaming agricultural adaptation in developing countries. In Africa for example, the Comprehensive Africa Agricultural Development Programme (CAADP), under the auspices of the New Partnership for Africa's Development (NEPAD), provides an excellent opportunity to mainstream and support agricultural adaptation (see: http://www.nepad-caadp.net/index.php). The four CAADP pillars (land and water management, market access, food supply and hunger, agricultural research) are all relevant to addressing climate change and food security at regional and country levels through CAADP country compacts. So far, 26 countries have either a draft or signed compact, investment plan or stocktaking report.

Institutional analyses of the case study countries all show that agricultural ministries have institutional presence from national to local level, and therefore are in a strong position to support local adaptation. With all adaptation options involving significantly building upon existing strategies for coping with climate variability and improving agricultural efficiency, agricultural institutions are best placed to undertake these actions. However, there is need to coordinate effectively with other sectors – such as meteorology and the environment – where most of the climate change responsibilities lie, as well as with local government structures.

At the national level, there should be harmonisation of publicly and privately provided funds, including vertical funds by private donors, funds from private businesses, and emerging, non-traditional development partners such as China and Brazil.

C. **The opportunities for private sector involvement in adaptation are vast, and private sector involvement is already evident at the global level.** But private sector opportunities at the country level need to be evaluated and quantified.

Several global private companies are already taking steps to harness opportunities provided by climate change by investing in biotechnology and seeds that are resistant to climate-related stresses. However, concerns are being raised about the ethical and environmental impacts of the way global private companies are positioning themselves. At the country level, cash-cropping systems provide a clear demonstration of the potential involvement of the private sector in adaptation from four angles:

1. Private sector players directly involved in the agricultural value chain will need to adapt their operations to changing climates. For example, in Rwanda's coffee systems, private coffee growers and coffee washing stations will be affected by climate change directly. Malawi's Lower Shire case study area has large private sector investments whose operations depend on water from a river that is climate-sensitive. Because competition for water among various activities is likely to intensify with climate change, private sector players will be part of a common local solution.

2. The profitability of private businesses not directly involved in production and processing of coffee in Rwanda will be affected by variations in the quality of export coffee that are caused by climate change. Businesses in developed countries that source their produce from developing country agriculture could also be indirectly affected if production or quality is affected by climate change. Investment by developed country businesses in the resilience of farmers within their supply chains helps to maintain security of supply and quality over a long period of time, in a similar way that investment in sustainable and ethical production methods also furthers this stability objective.
3. The private sector has another opportunity to be involved in adaptation through the provision of weather-indexed insurance schemes, as well as setting up rural savings schemes and other tailored financial instruments – a need identified in the Malawi case study.
4. The provision of adaptation technology is a function of the private sector. Examples include irrigation equipment, and solar- or wind-powered water pumping equipment for livestock watering points (Tanzania). If adequately funded, either through public funds or user payment schemes, installation of watering points in Tanzania represent business opportunities of more than $60 million to meet current needs, and could grow by about 10 times by 2020 with increasing climatic changes.

While country-level opportunities still need to be evaluated and developed, at the global level, harmonisation of private company investments in agricultural adaptation and development with global climate change and development priorities and ethics is required so that private investments are part of the solution and not the problem, and to avoid conflict between business and sustainability goals.

D. **Adaptation policies should harness private sector and market-based opportunities to promote adaptation, thereby reducing public demand for adaptation funds.**

While some country analyses show that some of the costs of adaptation fall under the private sector this is very limited, and there are no details about the incentives for private businesses to invest in agricultural adaptation. There is potential for market-based schemes, such as Fairtrade, to incorporate adaptation principles, especially in cash-based agricultural systems. Market-based initiatives could draw from both local (country) private funds as well as global private funding.

E. **Implementation and funding of agricultural development and adaptation activities at the country and local levels need not be separated, while institutional change at national level is required to ensure that climate change is integrated in all agricultural development activities, policies and development plans.**

Local communities, government, NGOs and donors are currently implementing and funding several agricultural projects that enable agriculture to cope with climate variability and agricultural inefficiencies. These activities overlap with the strategies required to adapt to climate change, or form the basis for future adaptation. It has been noted in Malawi that only eight out of the 6,300 donor-funded projects use the word 'adaptation', even though most claim that addressing food security also involves addressing climate change. Because of their strong linkages, and the inability to separate adaptation from agricultural development at the local level, funding for the two may also be difficult to separate. If this artificial division is made mandatory, especially in adaptation projects, then adaptation is *likely to provide only piecemeal solutions to a problem that is integrated with development issues. At the global level it may be desirable – in order to address the historical responsibilities for climate damages – to separate adaptation funds from development funds, but separating their deployment in a sector like agriculture may fragment action on a problem that requires holistic solutions.

At the same time, it has also been noted that the integration of climate change scientific information is highly limited at all levels. This information is either missing or is in a form that does not inform specific plans and actions. This limits planners and actors to short-term solutions that do not address likely future climatic changes. In several cases, either the exact impact of climate change on a specific agricultural system (e.g., coffee in Rwanda), or the attribution of impacts to climate change, e.g., flooding in southern Malawi and salinity in Bangladesh, is not clear. While adaptation to both climate and other drivers of agricultural stress is required anyhow, it is important that the scientific basis for adaptation in specific agricultural systems be strengthened over time.

F. **Global coordination and harmonisation across climate change policy processes, agricultural development and the private sector will deliver appropriate signals and resources that are require at country levels.**

As climate change funds are limited, the various sources have to be identified, channelled and utilised in developing countries in a coordinated way to avoid duplication and gaps. Coordination at the global level will also harness private sector resources while addressing some of the concerns being raised about the conduct and ethics of the private sector. Indeed, the private sector has an important role to play in adaptation.

7.3 Implications for global climate policy

The study concludes that planning agricultural adaptation should be done at country level, and any economic studies should be tailor-made to meet the planning and implementation needs of individual countries rather than that of donors. Capacity development at country level should be focused on aligning agricultural adaptation with existing agricultural development and wider country frameworks, and economic assessments need to focus on how to make this cost-effective by investing at relevant levels and involving a wider range of stakeholders, including the private sector. As the adaptation and development landscape is complex, economic studies will be more realistic when adaptation itself if properly framed, beyond simgle actions such as the use of technologies to improve crop yields.

The entry points for agricultural adaptation are infinite, as there are diverse agricultural systems such that adaptation actions and processes cannot be realistically shaped by top-down prescriptions. Apart from strategic priorities or areas of emphasis, this study – covering only five agricultural systems – has not been able to come up with a comprehensive list of all the adaptation actions that need to be supported, as these vary widely from country to country. In fact, global policymakers have a lot to learn from many years of agricultural development experience that developing countries have gone through. Similarly, as agricultural adaptation at the local level cannot be divorced from local food security pursuits, national and global coordination and harmonisation in these areas should not be separated. The separation of adaptation and development funding is an unavoidable aspect of the global climate change negotiations, but the imposition of this division at the local level adds to the complexity of disjointed projects and institutions.

The economics of adaptation still remains a major area that requires attention in order to inform policymaking and action. However, more value would come from focused economic analyses than from global costing studies, as there seems not to be a convergence of cost estimates. Focus on issues such as levels for investing and channels for deploying adaptation funds, incentives for pro-poor private sector adaptation investment, value chain adaptation, and others closer to the areas of action will go a long way in supporting action, while global costing studies should simply guide global fund-raising rather than being the main pre-occupation of policymaking.

Finally, the scope for linking adaptation and mitigation exists, but this needs to be considered carefully for different agricultural systems within the food security and development pathways of developing countries. While this study did not cover these linkages, it is an area that again needs investigation.

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