Chapter 16. Adaptation Opportunities, Constraints, and Limits

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Executive Summary

Adaptation opportunities, constraints and limits vary significantly across regions and sectors as well as through spatial and temporal scales. Those regions or sectors that encounter a disproportionate burden of constraints or limits may be particularly challenged to adapt to climate change. Low adaptive capacity due to poor problem orientation, limited entitlements to adaptation resources, institutional arrangements, or social and cultural factors may interact to impede adaptation efforts. In addition, teleconnections with respect to human and ecological vulnerability enable constraints and limits to be transmitted through space, and opportunities, constraints and limits may emerge and fade over time.

Currently perceived adaptation opportunities, constraints and limits are largely theoretical, socially constructed and context-dependent. While biophysical constraints and limits on adaptation responses are almost certain to exist, the available information is characterized by normative judgments and values which may not be

made explicit. This creates challenges for developing generalizable principles regarding adaptation constraints and limits or identifying and anticipating where and when constraints and limits may arise or be ameliorated.

Future rates of biophysical and socioeconomic change influence opportunities, constraints and limits to adaptation. The more rapid climate change progresses at global, regional and local scales, the more likely adaptation efforts are to be constrained or encounter limits. Adaptation will also be influenced by rates of demographic, social, economic and technological change that may introduce opportunities in some instances, but also constrain adaptation in others.

Policies and measures that address adaptation constraints and limits are fundamental to advance adaptation processes. While traditional emphasis in adaptation has been on discrete adaptation options to reduce the adverse consequences associated with climate impacts, less attention has been devoted to the integrated management of the range of constraints that impede the implementation of such options.

There may be reasons for imposing constraints or limits on certain types of adaptation policies and measures. The emergence of climate change impacts could create demand for certain types of adaptation policies and measures that are associated with negative externalities or are otherwise inconsistent with broader societal objectives, including sustainability. Anticipation of such adaptation demands, the introduction of constraints to their implementation, and the early identification of alternatives may assist in avoiding maladaptation.

Maintaining flexibility with respect to adaptation policies and measures may make adaptation more effective. The difficulty in anticipating opportunities, constraints and limits creates challenges for the *a priori* identification of successful adaptation pathways. As such, preserving a variety of adaptation options is likely to lead to the most robust adaptation outcomes. Different approaches to flexible decision-making (e.g., adaptive management or robust decision-making) may be more or less useful in different adaptation contexts.

Message needed re: adaptation/mitigation interactions

16.1. Introduction

Chapter 14 showed that adaptation to climate change has become a necessary consideration in all parts of the world, and that various options exist to address adaptation needs. Chapter 15 presented adaptation planning and implementation as an iterative process, and concluded that adaptation constitutes more than just implementing an adaptation option. Adaptation is not a one-off solution, and the mere existence of adaptation options does not mean these options are automatically implemented as soon as the need arises. Opportunities may be missed, and there are constraints and limits that hinder adaptation. This chapter assesses the nature and cause of these constraints and limits, and the opportunities that exist or can be created to advance adaptation planning and implementation. In doing so, this chapter defines these three terms as indicated in Box 16-1.

_____ START BOX 16-1 HERE _____

Box 16-1. Adaptation Opportunities, Constraints and Limits Defined

In the context of adaptation to climate variability and change:

- An opportunity is a set of circumstances that makes successful adaptation possible or easier to achieve. Adaptation opportunities can be created by deliberate or unintentional public or private interventions. (Note that adaptation opportunities are not the same as opportunities arising from climate change, which would commonly be referred to as potential benefits of climate change.)
- A constraint is any socio-economic or biophysical restriction or limitation that makes adaptation responses more difficult or expensive to implement, and/or reduces the number of adaptation options. When adaptation is constrained, adaptation objectives remain achievable.
- A limit is socio-economic or biophysical restriction or limitation that makes meeting adaptation objectives impossible. There are absolute limits and mutable limits.

_____ END BOX 16-1 HERE _____

This chapter first presents a framing of adaptation opportunities, constraints and limits, followed by a summary of how the Fourth Assessment Report (AR4) and the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) assessed these issues. Section 16.2 then synthesizes adaptation opportunities, constraints and limits as assessed by the sectoral and regional chapters in this report. Opportunities for adaptation are then assessed in more detail in Section 16.3, while Sections 16.4 and 16.5 assess adaptation resources and constraints, and limits to adaptation, respectively. Section 16.6 discusses the effects of mitigation on adaptation needs, opportunities and potential, which is followed by an assessment of ethical dimensions of adaptation constraints and limits in Section 16.7. The concluding section, Section 16.8, assesses research that has identified ways of seizing opportunities and overcoming constraints and limits.

16.1.1. Background and Rationale

Adaptation is a process operating at many timescales, connecting across society, and linking adjacent and widely separated places (Adger *et al*. 2009b; Allen *et al*.; Orlove 2009; Wilbanks and Kates 2010). The associated opportunities, constraints and limits mirror these dynamic and complex traits as they themselves change. In order to maximize decision relevance, our summary takes as its entry point the view of actors as they consider response strategies over near, medium and longer terms. Actors maybe individuals, communities, organizations, corporations, NGOs, governmental agencies, or other entities responding to real or perceived climate-related stresses or opportunities as they pursue their goals (Blennow and Persson 2009; Frank *et al*. 2011; Patt and Schroter 2008). These actors may simultaneously make near-term adaptations within constrained or limited situations while anticipating or working to achieve changes to those restrictions. Actors may also be planning adaptations or building adaptive capacity relevant to the long-term (Moser and Ekstrom 2010). Therefore, it is necessary to consider diverse timeframes for possible social, institutional, technological and environmental changes. These timeframes also differ in the types of uncertainties that are relevant, ranging from those of climate scenarios and models, possible thresholds, nonlinear responses or irreversible changes in social or environmental systems, and the anticipated magnitude of impacts associated with higher or lower levels of climate change (Briske *et al*. 2010; Hallegatte 2009; Meze-Hausken 2008).

Within these dynamic conditions, there is a wide universe of potential adaptation options both to avoid losses and to pursue opportunities. The set of options available at any point in time for a given planning horizon is shaped by the current circumstances of governance, economic systems, environmental and socio-political conditions, as well as the actors' capacities. These capacities reflect endogenous factors such as an actor's culture, perceptions, well-being, the characteristics of organizational structures as well as an actor's access and control over exogenous resources including financial/economic, environmental goods and services, technology, infrastructure, information, and workforce education and training (Adger *et al*. 2009b; Orlove 2009; Smit and Wandel 2006; Wilbanks and Kates 2010). (Look up O'Brien 2009 in Adger *et al*. re values). Such capacities, to the distribution of resources, and broader social and environmental circumstances shape opportunities, constraints and limits. The range of adaptation options changes as actor capacities, social context and climate-environment conditions vary. While some adaptation options will aim to secure the status quo, some will reflect changing goals (Garrelts and Lange 2011). Some of the adaptations may be oriented to engaging new opportunities while others may lead to future constraints or limits by promoting the lock-in to a technology, fostering path dependence around a set of strategies, leading to unsustainable circumstances, or resulting in irreversible changes (Berkhout 2002; Chhetri *et al*. 2010; Eriksen *et al*. 2011). Adaptations are also likely to be combinations of activities as it will not be possible to assure complete safety and insurance or other supports for recovery will accompany efforts to build resilience.

The adaptation process may involve extending resources and capacities to take advantage of emerging opportunities as well as avoiding undesirable or dangerous situations. All investments and changes come with tradeoffs, compromises and restrictions. Here we focus on those that that are directly or indirectly related to climate changes and restrict adaptation options by either requiring significant tradeoffs among an actor's set of goals or giving up a goal. The influence of climate change may be to make a tradeoff more substantial or to create a new tradeoff relationship (Hamin and Gurran, 2009).

Climate change will lead directly and indirectly to a diverse set of opportunities, options for an actor to more fully achieve their goals. Adopting agriculture practices supported by greater rainfall and/or warmer temperatures, increasing justification for "no-regrets" activities that will also benefit current problems, joining the green jobs sector, or entering an emerging technical area are possibilities emerging from climate and accompanying social changes. Climate trends as well as new discoveries, innovations, policy changes, leadership shifts and disasters will affect the timing, duration and scale of the opportunities. The characteristics of these processes offer some potential for planning as well as a level of unpredictability across timeframes. (References to be added)

The key terms in the title of this chapter -- opportunities, constraints and limits -- are widely used in scientific and standard communication and each has many synonyms, including frequently used terms such as barriers and thresholds. The definitions used here draw on key concepts from scientific assessment including specifying temporal frames and actor's perspectives, and integrating the standards set forth in the framing language of the IPCC[1], hence referring to "realistic response" as the standard. While such conceptual framing can be useful in structuring understanding, a major challenge lies in our ability to differentiate between constraints and limits. Limits are difficult to define because their identification depends on assessment of adaptive capacity, itself a latent trait that is not fully expressed until needed; defining boundaries of systems which are known to interact over wide spatial, temporal and social reaches; and unknowns and uncertainties about the dynamics of systems. Studies of ecological limits are dominated by analyses of single species which do not engage broader ecosystem dynamics and change. The dynamics, complexity and diversity of factors influencing environment–society relationships are generated through subjective, essentially political, processes that do not support broad generalization or fixed definitions (Adger *et al.,* 2009b; Meze-Hausken, 2008).

[INSERT FOOTNOTE 1 HERE: "The General Assembly […] endorses action of the World Meteorological Organization and the United Nations Environment Programme in jointly establishing an Intergovernmental Panel on Climate Change to provide international coordinated scientific assessments of the magnitude, timing and potential environmental and socio-economic impact of climate change and realistic response strategies […]." United Nations General Assembly 43rd session resolution, 6th December 1988.]

A constraint restricts the range of realistic options available to an actor within a given decision timeframe (horizon) and forces tradeoffs among actor goals. (Meze-Hausken, 2008) includes perceptions of change, wants, choices, needs, options and economic capacity as "subjective thresholds. The set of options which are normatively viewed as "realistic" will be defined by actors depending on their circumstances and perspectives. For the purpose here, we think of them in the broadest terms as those options that expected to reduce overall harm (Eriksen *et al.,* 2011; Fazey *et al*., 2010). These tradeoffs may take the form of reduced effectiveness (e.g. less risk reduction, less comprehensive coverage of need), a shift in priorities (e.g. allocating a higher percentage of water resources to support low carbon energy instead of increased agricultural irrigation) or lower desirability (e.g. huge seawalls that block views or substantial modifications of historic areas) of an adaptation option. These constraints are products of social and environmental context as well as an actor's capacities. These may be physical, technological, economic, institutional, legal, cultural, or environmental conditions (Adger *et al*., 2009a; Meze-Hausken, 2008; Moser and Ekstrom, 2010; Patt and Schroter, 2008; Yohe and Tol, 2002).

A limit is reached when there are no further realistic adaptation options for an actor given that actor's capacities, social and environmental context, and the decision timeframe (or horizon) required to act in order to avoid adverse impact. Reaching a limit requires giving up a goal in order to continue to pursue others. These limits may be created physical, technological, economic, institutional, legal, cultural, or environmental conditions (Adger *et al.,* 2009a; Meze-Hausken, 2008; Moser and Ekstrom, 2010; Patt and Schroter, 2008; Yohe and Tol, 2002). For example, a coastal community may choose to retreat rather than attempt to protect in place. Some limits are mutable or flexible such that while they restrict the current decision, they may be overcome with time. (Review on the need to abandon current livelihoods "Is climate change the straw that broke the camel's back"? (Blackwell. 2010)). Many processes work to alter these flexible limits including research and development to support the availability of a new technology, review of governance to direct changes in legal/regulatory rules, creation of funds to support adaptation actions. We contrast these mutable/flexible limits with a set of absolute limits that cannot be altered. Examples of absolute limits include water supply in fossil aquifers, the range of a species, limits to retreat on islands, loss of genetic diversity, or the tolerance of coral species to temperature and acidity. Many of these absolute limits will also be irreversible such that failure of mitigation or adaptation efforts to avoid them will result in permanent changes. Figure 16-1 provides a simplified schematic view of the relationships between options, constraints and limits. Where constraints are higher, adaptation may be less effective or efficient (Moser and Ekstrom 2010), there maybe fewer options available or tradeoffs maybe greater (Kasperson *et al*., 1995), and in the face of limits, there are no options that do not require giving up an important goal.

[INSERT FIGURE 16-1 HERE
Figure 16-1: An actor's view of adaptation constraints and limits at a given point in time.]

16.1.2. Summary of Relevant AR4 and SREX Materials

Unlike the current assessment, the Fourth Assessment Report (AR4) did not have a chapter dedicated specifically to adaptation opportunities, constraints and limits. Relevant literature was assessed in particular in the Working Group II chapter 'Assessment of adaptation practices, options, constraints and capacity' (Adger *et al*., 2007). The sectoral and regional chapters of Working Group II also assessed adaptation issues, including constraints, according to a common template. This section summarises the key findings on a regional basis; Section 16.2 provides an updated cross-sectoral and cross-regional synthesis based on the corresponding chapters in this report.

The Summary for Policymakers of Working Group II concluded that there are "formidable environmental, economic, informational, social, attitudinal and behavioural barriers to the implementation of adaptation" and that for developing countries, "availability of resources and building adaptive capacity are particularly important" (Parry *et al*., 2007). These findings were based primarily on the chapter by Adger *et al*. (2007). Their key conclusion, as relevant to this chapter, was as follows:

> **There are substantial limits and barriers to adaptation (very high confidence).**
>
> High adaptive capacity does not necessarily translate into actions that reduce vulnerability. For example, despite a high capacity to adapt to heat stress through relatively inexpensive adaptations, residents in urban areas in some parts of the world, including in European cities, continue to experience high levels of mortality. There are significant barriers to implementing adaptation. These include both the inability of natural systems to adapt to the rate and magnitude of climate change, as well as technological, financial, cognitive and behavioural, and social and cultural constraints. There are also significant knowledge gaps for adaptation as well as impediments to flows of knowledge and information relevant for adaptation decisions.
>
> New planning processes are attempting to overcome these barriers at local, regional and national levels in both developing and developed countries. For example, least-developed countries are developing National Adaptation Programmes of Action and some developed countries have established national adaptation policy frameworks.

The sectoral and regional chapters further substantiated this conclusion. For example, the chapter on Small Islands by Mimura *et al*. (2007) found that there are several constraints to adaptation that are inherent in the very nature of many small islands, including small size, limited natural resources, and relative isolation. Drawing from Barnett (2001) and Barnett and Adger (2003), Mimura *et al*. (2007) also noted that global economic processes such as market liberalization, together with global warming, sea-level rise and possibly increased frequency and intensity of extreme weather events, make it difficult for autonomous small islands to achieve an appropriate degree of sustainability.

For Africa, Boko *et al*. (2007) found that adaptation is successful and sustainable when linked to effective governance systems, civil and political rights and literacy. However, there is also evidence of an erosion of coping and adaptive strategies as a result of varying land-use changes and socio-political and cultural stresses. Continuous cultivation, for example, at the expense of soil replenishment, can result in real "agrarian dramas" (e.g., Rockström 2003). Boko *et al.* (2007) noted that traditional coping strategies may not be sufficient and may lead to unsustainable responses in the longer term. In addition, they found that limited scientific capacity and other scientific resources also frustrate adaptation (e.g., Washington *et al.* 2004, 2006).

The chapters on Asia and Latin America confirmed the challenge faced by developing regions. For Asia, Cruz *et al.* (2007) noted that the poor usually have very low adaptive capacity due to their limited access to information, technology and other capital assets, making them highly vulnerable to climate change. For Latin America, Magrin *et al.* (2007) also found that socio-economic and political factors seriously reduce the capability to implement adaptation options. For example, in the agricultural sector, particularly for small producers, these factors include limited availability of credit and technical assistance, and low public investment in infrastructure in rural areas (Magrin *et al.* 2007).

Also in the industrialized part of the world, adaptation faces constraints and limits. For example, Hennessy *et al.* (2007) found that while adaptive capacity in Australia and New Zealand has been strengthened, four broad barriers to adaptation remain: (i) a lack of methods for integrated assessment of impacts and adaptation that can be applied on an area-wide basis, (ii) a lack of well-developed evaluation tools for assessing planned adaptation options, such as benefit-cost analysis, incorporating climate change and adapted for local and regional application, (iii) ongoing skepticism about climate change science, uncertainty in regional climate change projections, and a lack of knowledge about how to promote adaptation, and (iv) weak linkages between the various strata of government, from national to local, regarding adaptation policy, plans and requirements.

Likewise, for North America, Field *et al.* (2007) identified social and cultural barriers, informational and technological barriers, and financial and market barriers. The chapter on Europe also mentioned the limits faced by species and ecosystems due to lack of migration space, low soil fertility and human interventions (Alcamo *et al.* 2007). Finally, in the chapter on the Polar Regions Anisimov *et al.* (2007) noted that indigenous groups have developed resilience through sharing resources in kinship networks that link hunters with office workers, and even in the cash sector of the economy. However, they concluded that in the future, such responses may be constrained by social, cultural, economic and political communities externally and from within.

A few other AR4 chapters assessed literature relevant to this chapter. The chapter 'Inter-relationships between adaptation and mitigation' (Klein *et al.*, 2007) discussed the possible effect of mitigation on adaptation (an issue also considered by Working Group III, in particular by Fisher *et al.*, 2007 and Sathaye *et al.*, 2007). Finally, the chapter 'Assessing key vulnerabilities and the risk from climate change' (Schneider *et al.*, 2007) outlined how the presence of adaptation constraints and limits is a contributing factor to vulnerability, possibly resulting in significant impacts. The findings of these chapters are not summarized here but in Sections 16.6 and 16.8 (?), respectively.

The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) … [to be done once the report has been finalized]

16.2. Synthesis of Adaptation Opportunities, Constraints, and Limits

[THE TEXT BELOW IS HERE AS A PLACEHOLDER. THE IDEA IS TO SYNTHESIZE RELEVANT INFORMATION FROM THE SECTORAL AND REGIONAL CHAPTERS IN TABLES 16-1 and 16-2.]

[INSERT TABLE 16-1 HERE
Table 16-1: Cross-sectoral synthesis.]

[INSERT TABLE 16-2 HERE
Table 16.2: Cross-regional synthesis.]

To be added to Tables 16-1 and 16-2:

- Captions need to explain (i) types of constraints, (ii) link between constraints and opportunities & limits, (iii) suggestion for synthesis (including consideration of ease of addressing constraints).
- Matrix cells will contain short descriptions of specific constraints, including references to (sub-)section numbers in the relevant chapter.

(More) references to be added to the following Subsections 16.2.1 and 16.2.2.

16.2.1. Cross-Sectoral Synthesis

16.2.1.1. Opportunities, Constraints, and Limits within Sectors

Key vulnerabilities can be linked to systemic thresholds or with "normative thresholds" (Parry *et al.*, 2007). Vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change. The identified key vulnerable systems are global biophysical systems, marine ecosystems and biodiversity, distribution of food supply. Small Island is key regional vulnerable system while Greenland Ice Sheet and Meridional Overturning Circulation have been identified as key vulnerable geophysical systems to climate change (Parry et al, 2007). It is revealed that damage to ecosystem and risk of extinction of species with similar range of temperature rise vary by region (Midgley and Thuiller, 2010; Hughes, 2010; Alkemade *et al.*, 2010; Ni *et al.* 2000). Crop productivity is projected to increase slightly at mid- to high latitudes depending on the crop with local mean temperature increases of up to 1-3°C and then decrease beyond 3°C while at lower latitudes particularly in seasonally dry and tropical regions crop productivity is projected to decrease for even small local temperature increases (Hare *et al.*, 2011). About 75 to 250 million people in Africa, 0.1 to 1.2 billion in Asia, 10 to 80 million in Latin America will face more severe water shortages by 2020 while water sources will be seriously compromised due to sea level rise and change in rainfall and evapotranspiration in Small Island (Parry *et al.*, 2007).

The ultimate objective of the climate change convention is to prevent dangerous anthropogenic interference to climatic system which will allow ecosystems to adapt naturally, ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (UN, 1992). Over the last more than two decades, different groups of scientists attempted to define dangerous climate change and acceptable limits to warming and researches are being continued (Rijsberman and Swart 1990; WBGU 2003; Jain and Bach 1994; WBGU 1995; Hansen *et al.* 2007; Hansen *et al.* 2008). Key finding of the available assessment that risks rise substantially between 1°C and 2°C increase of global mean temperature above pre-industrial level and to the point where a level of non acceptability or threshold is reached at close too or even below 2°C warming.

The most vulnerable sectors to climate change are: a) water in the dry tropics, b) agriculture in low latitudes, c) human health in poor countries, d) areas where activities depend on sensitive ecosystems, especially tundra, boreal zones, mountains, and e) ecosystems already stressed, such as mangroves and coral reefs (IPCC, 2007b). Low-lying coastal areas and mega-deltas in Asia, Sub-Saharan Africa and many Small Islands States would be more vulnerable due to projected changes in annual average river runoff and water availability, decrease at crop productivity in dry and tropical regions, exposure of coastal areas and people to cyclone, storm surges, erosion, coastal subsidence and sea level rise. Coastal areas, especially heavily-populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers (Parry *et al.*, 2007).

There are distinct difference of existing adaptation measures between developed and developing countries. Adaptation measures in low income countries are characterized by reactive adaptations measures to short term motivation, happening at individual level with weak government involvement, and activities are concentrated to agriculture, fisheries and forestry sectors. Dominated activities include avoiding or retreating, coping or accommodating, adjusting, spreading risk and securing income or resources. Primarily it includes community-level mobilization mechanism rather than institutional, governmental or policy tools. Adaptation measures in high income countries are characterized by more anticipatory measures in response to long term climatic change such as sea level rise and temperature and are involved non-resource sectors such as transportation and infrastructure. Dominated activities are reducing risk, building partnership, improving monitoring, strengthening institutions, enhancing research, promoting awareness. For example adaptation research undertaken in European countries can help informed decision making by farmers, agribusiness and policy makers with implication over a range of timeframes from short-term tactical to long-term strategies (Easterling at al., 2007, Lobell *et al*., 2008). Adaptation measures are significantly low in middle income countries due low level of access to fund though their vulnerabilities are similar to low income countries (Berrang-Ford *et al*., 2011; Ford *et al*., 2011). It is more likely that high income countries are to be investing in proactive adaptations coordinated at a government level than the reactive responses common in low income nations (Stern, 2006; Costello *et al*., 2009; IPCC, 2007a,b,c). However, adaptive capacity vary among the high income countries and studies that quantified adaptive capacity based on generic socio-economic indicators (Schröter *et al*. 2003; Metzger *et al*. 2006) suggested that the Mediterranean regions had a lower adaptive capacity than temperate and Nordic regions. Reidsma (2007) showed that the actual impacts of increasing temperatures are not more severe in Mediterranean compared to temperate regions, suggesting adaptation of farmers to prevailing conditions.

Most common and often referred adaptation practices and options in cross-sectoral nature are a) improvement of systematic observation and monitoring, b) early warning systems, c) information and communication, d) modeling and forecasting, e) emergency response, and f) planning and designing (UNFCCC, 2007; UNFCCC, 2007b). Improvement of systematic observation and monitoring systems as technologies for adaptation cut across coastal zone and marine ecosystem, agriculture and fisheries, biodiversity and monitoring species for terrestrial ecosystems and human health sectors. Development and/or improvement of multi-hazard early warning systems linked with other national and global systems supports adaptation for agriculture and fisheries, water resources, coastal zone, human health and infrastructure. Information and communication including various databases and one-stop web-based systems which draw together guidance and tools to aid adaptation work including provision of climate data and the use of new climate data management systems. Forecasting and modeling tools includes global data processing and forecasting systems, decision-making tools integrating climate information, modeling of monsoon rainfall and ocean modeling systems. Introduction of new technologies to support adaptation planning and to develop risk atlases supports adaption to all sectors.

Multi-sectoral adaptation options relate to the management of natural resources which span sectors, for example, integrated water resource management and integrated coastal zone management while reactive and standalone efforts to reduce climate-related risks to coastal systems are less effective than responses which are part of integrated coastal zone management (ICZM), including long-term national and community planning (Bijlsma *et al*., 1996; McLean *et al*., 2001, Kay and Adler, 2005). IWRM make it an ideal overarching framework in which to evaluate, design, implement and monitor adaptation strategies for climate impacts on water resources. Building communities of practice around IWRM can facilitate the mainstreaming of climate adaptation strategies into sustainable development efforts, providing synergy in awareness-raising, capacity-building and in the creation of social, political and institutional environments receptive to technological innovation (UNFCCC, 2006).

Mainstreaming climate change into national, sectoral and local development has emerged over time as several adaptation measures happening now support the argument that adaptation is taking place in response to multiple stresses and are reinforcing the importance of mainstreaming adaptation (Dovers, 2009, Tompkins *et al*., 2010). Several studies revealed that there is a mismatch between national statements on adaptation and local action to address climate change impacts meaningfully. Adaptation intervention addressing short term risks over long term strategic planning potentially increasing vulnerability and making future adaption more difficult. Institutional barriers along with limited consideration of future climate change scenarios in adaptation planning and intervention create potential maladaptation (Berrang-Ford *et al*., 2011). Ecosystem based adaptation has also emerging as key adaptation measure along with other options.

The degree of adaptation depends on the adaptive capacity of each country, region, or exposed sector and adaptive capacity relies on various factors, such as financial and human resources, scientific knowledge, access to information, technology, social institutions and infra-structure. For example, european farms with higher yields would have a higher capacity to adapt to changing conditions and in general farms with higher intensity, farm size and more arable land obtain higher crop yields (Reidsma *et al*., 2007). Barriers to adaptation are distinct in nature between developed and developing countries. Institutional challenges are widely noted as common barriers to adaption faced by developed countries, often involving significant time to negotiate and consult with various interested parties. Changing and creating institutions and present political short-sightless also often limits planning for long term risk. However, financial barriers, lack of information on the necessity to adapt, knowledge about available options and the ability to implement most suitable ones are appears not problems for developed countries (Berrang-Ford *et al*., 2011).

16.2.1.2. Opportunities, Constraints, and Limits Arising from the Interaction among Sectors

Engineering of protective structures such as seawalls and dikes protect the population and productive system but put adverse effect on natural system limiting sediment discharge and subsequently causing erosion at the river mouths in many coastal cities and the Asia and Pacific Cities (Nunn *et al*., 2006) and may also eliminate valuable natural wetlands in future. The collapse of seawalls also fund very common in many Pacific Islands. A cheaper and more effective long-term solution is planting mangroves along affected shorelines (Nunn *et al*., 2006).

The industry and agriculture sectors may be mutually influenced. For example, the tart (sour) cherry production is highly sensitive to climate extremes and threshold events, particularly to extended springtime warm periods followed by cold temperatures that cause buds to lose hardiness and become susceptible to frost damage. In addition, the tart cherry industry reflects the challenges encountered by, and limited adaptation strategies of, any industry that has long planning horizons and long-term investments. Tart cherry orchards have life cycles of 20–30 years with limited adaptation options for growers and other industry participants. The tart cherry industry also is currently undergoing a substantial evolution in terms of changing major production areas with large potential regional and international shifts of production and international trade (Winkler et al, 2010).

Importance are give to local factors in assessing impacts, vulnerabilities and options for adaptation in climate change literature (Parry *et al*., 2007). It is evident that most studies are assessing both climate impacts and adaptation potential at the local level. There is reason to believe that local economic studies do not scale up but Aaheim *et al*. (2007) examined how an increase in the forest biomass affected the economic outcome for the forestry sector, when economic agents adapt in order to maximize profits and trade their products in the world markets as well as profits at the local level increased. However, looking at the global level and assuming that additional biomass production would be a widespread phenomenon, the economic gains to private actors disappeared, because of an excess supply leading to decreasing prices. The benefits were captured by the biomass users as the prices went down. The forestry owners suffered a loss in the end. This pattern may not be unusual, and indeed is likely to be seen across a wide range of both adaptation- and mitigation-related decisions. We need more research to understand the complex way in which local adaptation aggregates to the global level (Yohe et al, 2007).

Adaptation research undertaken now can help inform decision by farmers, agribusiness and policy makers with implication over a range of timeframes from short-term tactical to long-term strategies (Easterling *et al*., 2007, Lobell *et al*., 2008). In this context, is important to align the scales (spatial, temporal and sectoral) and reliability of the information with the scale and nature of the decision. For example, short-term climate adaptation by farmers may be accomplished by taking into account local climate trends and projected climate changes, or climate forecasting at scales from daily to inter-annual. Yields simulated using present-day climate data from Australia differed from those simulated using long-term data. These differences varied regionally and are likely to be the result of spatial differences in observed warming and drying trends on underlying paddock management and edaphic and climatic systems (Crimp et al, 2008, Laing *et al*., 2009).

Current variations in climate already cause major problems for many households and communities, resulting in lack of access to water for household consumption and irrigation. In many areas water scarcity and related problems have been worsening because of population growth and increased use of water for irrigating agricultural crops. New problems have also arisen including pollution from chemicals associated with intensive crop production. Due to climate change, there is increased attention to the risks associated with agricultural intensification, water scarcity and other risks associated with health and nutrition and environmental quality. That is, there is increasing appreciation of the inter-relationships between the different risks. Moreover, in many regions there is no sound policy and institutional foundation for dealing with current climate variability. In such cases, adapting to climate change will be even more complex (Hedger, 2008).

The Global Impact Models which encompasses activities in many sectors covering energy, transport, urban development, water, agriculture, forestry, industry, economic policy and social and human development sector . Based on individual modules for different climate variables, sectoral features and climate response functions for each sector it shows that the 2°C global-mean warming projected for 2060 will result in net market benefits for most OECD countries and net market damages for most non-OECD countries. There has been limited attention to disaggregating the overall effects of climate change and consider economic and social impacts at the household level and how to manage those (World Bank, 2007).

Adaptation assessment and planning must address issues and systems at a wide range of spatial scales: (1) the global scale system, (2) regional scale trans-boundary water basins, (3) national scale production and social wellbeing systems, (4) local communities and (5) site-specific exposure units such as farms. Similarly, adaptation planning needs to consider a wide variety of time horizons: (1) season to several years for farm activities and provisions of health services, (2) decadal-scale tourism and protected area development and (3) infrastructure projects ranging from a few decades to over a century (Lu, 2011). In addition, the process of adaptation is also multi-dimensional. To be sustainable, adaptation to climate change need to be integrated into ongoing planning process, horizontally across different climate sensitive sectors (e.g. agriculture, energy, tourism, public health) and vertically across different administrative levels (e.g. local, national, regional and global). According to Agrawal (2008), only 20% of projects described in the NAPA documents incorporate local institutions as the focus of adaptation projects; even fewer identify local institutions as agents or partners in facilitating adaptation. The modest role envisaged for local institutions is surprising given that local institutions (and not just central ministries) would have to play a key role in many of the sectors targeted by NAPAs (agriculture, water, small-scale infrastructure, etc.). For some reason, the supposedly widespread consultations that went into the production of the NAPAs did not result in a stronger role for local level adaptation and local institutions (Agrawal, 2008).

16.2.2. Cross-Regional Synthesis

16.2.2.1. Opportunities, Constraints, and Limits within Regions

Cross-regional synthesis revealed that development of new drought-resistant varieties; development and promotion of alternative crops; development of new heat-resistant varieties; change to heat-tolerant breeds; and development of wind-resistant crops can be transferred from one geographical region to another. Similarly soil moisture conservation technologies e.g., through mulching, desalination of sea water, conservation of groundwater through artificial recharge, education for sustainable water use can be beneficial for more than one regions. An international surveillance system for disease emergence is a key cross-regional adaptation measures (Parry *et al*., 2007).

Much recent adaptation research has concentrated on understanding the value and feasible development of broad-scale adaptation options for agricultural production (Easterling *et al*., 2007; Howden *et al*., 2007). Each production region has additional constraints that must be identified, such as infrastructure (e.g., production methods and technology), land use, institutions (e.g., trade practices) and local and national politics. A synthesis of studies for cropping system indicate first that the potential benefits of adaptation in temperate and tropical wheat-growing system are similar and substantial (averaging 18%), even though the likely adaptation rates may differ; and second, that most of benefits of marginal adaptation within existing systems accrue with moderate climate change, and there are limits to their effectiveness under more severe climate changes (Howden, 2007).

16.2.2.2. Opportunities, Constraints, and Limits Arising from the Interaction among Regions

The impacts of climate change and adaptation differ greatly among regions. Over the last years the increases losses from weather related extreme events, coupled with limited coping capacity suggest a need for strong adaptation commitments. Numerous studies show a significant climate-change signal in natural disaster events (Schönwiese *et al*. 2003; Solomon *et al*. 2007). There is evidence of rising losses of extreme weather events and many regions and sectors in Europe are vulnerable to natural hazards (EEA 2004; EC, 2007a). In this context, in order to minimise future losses and impacts as projected to be exacerbated by climate change, it is important to improve upon the management of current and future climate adaptation. Managing disaster risk at global and regional level is considered apriority area for adaptation strategy, which call for early actions response in order to prevent significant future costs associated with reactive unplanned adaptation (Aakre at al, 2010).

At the regional level, some risks are potentially catastrophic: major declines of food production in entire regions of Africa, advanced desertification of large regions, or the drying up of rivers that supply regions and cities with water. Such regional disasters would overwhelm entire countries, and some of the most adversely affected countries stand at risk of dramatic upheavals without help (Heltberg at al, 2009).

Current production regions may no longer be profitable in a changed climate and may be replaced. Therefore, potential new production regions also must be assessed in light of projected changes in climate and possible future adaptations, and weather/climate dependency models will need to be developed and/or validated for these new regions (Winkler et al, 2010). Cline (2007) applies agricultural impact models, combined with climate model projections, to develop estimates for agricultural impacts in more than 100 countries. Agricultural productivity for the entire world may decline from levels otherwise reached by between 3 and 16 percent by the 2080s. Developing countries, however, many of which have average temperatures that are already near or above crop tolerance levels, are predicted to experience an average 10 to 25 percent decline in agricultural productivity by the 2080s. Since agriculture constitutes a larger fraction of GDP in developing countries than in industrial countries, the projected decrease in productivity will impose larger relative income losses, with important micro-, meso- and macro-economic implications. Some developing countries face very large declines in productivity: India could see a drop of 30 to 40 percent in agricultural production potential; Sudan 56 percent reduction; Senegal 52 percent (Heltberg et al, 2008).

16.3. Opportunities for Adaptation

16.3.1. The Options Universe

Adaptedness to climate is a normal feature of societies, evident in cultures, norms and activities everywhere. Beyond this, the idea of climate change is widely-understood, with consequences for "…the full parade of human endeavours, institutions, practices and stories." (Hulme, 2009:322). In this sense, adaptation to climate change includes not just tangible actions – such as the building of a higher river levee as a precaution against changed risks of flooding – but also intangible adjustments – such as the changed landscape values as a result of higher levees (Brander, 2011), or the changing sense of (in)security of residents living behind the levee. Opportunities for (and limits to) adaptation therefore have tangible as well as intangible dimensions (O'Brien, 2009). Values will change over time, partly due to the experience of climate change and human and ecosystem responses to it, and these changed values will influence what are viewed as effective or acceptable adaptations.

To define adaptation options we take as a starting point the IPCC (2001) definition of adaptation as being adjustments that are concerned with reducing vulnerability to climate change-related risks, building resilience in the face of climate damage or hazard, and exploiting new opportunities that may arise as a result of climate change. We also assume that adaptation involves some change in physical, ecological or social systems, even though what may be aimed at is the maintenance of a particular 'valued attribute' (Füssel, 2007), such as a given level of flood protection.[2] It follows that adaptation options are adjustments or changes in taste, norms, behaviour, practice, policy, technology, organisation or process that may lead to one or other adaptation goal. This can include small incremental changes in the short-term, or radical, disruptive changes over the longer term. The greater the vulnerability or opportunity, the greater will be the potential for adaptation (see Figure 16-2).

[INSERT FOOTNOTE 2 HERE: Adaptation may be intended to maintain a given level of vulnerability, resilience of welfare, it may seek to enhance the status quo (providing to better levels of flood protection), it may provide for a new 'optimal' set of conditions (taking costs and benefits into account), or it may lead to a decline in conditions (a sign that certain limits to adaptation have been reached). Which of these ultimate goals is chosen will be determined by the preferences and decision-making of relevant actors (O'Brien, 2009).]

[INSERT FIGURE 16-2 HERE
Figure 16-2: Timeline illustrating the lifetimes (sum of lead time and consequence time) of different types of decisions, compared with the time horizons for some global environmental changes, and the changing implications for adaptation (Stafford-Smith *et al.*, 2011:p 199).]

What is regarded as an adaptation option by a given actor depends on the goal of adaptation, but also on attitudes to uncertainty and risk, how strong the causal link between the adaptation and achieving an adaptation goal is believed to be, and the characteristics of decision-making about risk (Stafford-Smith *et al.*, 2011).[3] Adger *et al.* (2007) argue that adaptation goals are always socially-contingent. What the goal of adaptation should be will depend on diverse and incommensurable values held about the social or environmental goals that may be secured through adaptation. For example, rising temperatures may lead to a changing distribution of anopheles mosquitoes, the main vector for malaria (Tonnang *et al.*, 2010). One adaptation option might be to change land-use practices, for instance by limiting the cultivation of natural swamps (Patz and Olson, 2006). There are likely to be differing views about the feasibility of drainage as an adaptation option. But as this example makes clear, the trade-off is not just between two valued attributes (in this case health protection versus nature conservation), but depends also on a wide range of other questions: whether the risk of the spread of malaria is well-established (Gething *et al.*, 2010); whether the risk of malaria is viewed as serious; whether swamp drainage is seen as an effective means of risk management; whether there are other options for managing the risk of malaria; what the costs of drainage are relative to the costs of avoided malaria cases, and so on.

[INSERT FOOTNOTE 3 HERE: Hallegatte (2009) defines five strategies in adapting to climate change: '(i) selecting 'no-regret' strategies that yield benefits even in absence of climate change; (ii) favouring reversible and flexible options; (iii) buying 'safety margins' in new investments; (iv) promoting soft adaptation strategies, including (a) long-term (perspective); and (v) reducing decision time horizons' (p. 240).]

The universe of adaptation options includes adjustments that reduce perceived risks associated with climate change (Doria *et al.*, 2009), as well as adjustments that seek to take advantage of changing climate to enhance welfare and resilience. Recent research has shown that climate-society interactions are complex, uncertain and non-deterministic (Conway and Schipper, 2010). This has significant implications for climate adaptation action. Greater emphasis is being laid on low-regret options and reducing vulnerability to current climate variability, as well as a building on the social and economic basis for livelihood security over the long term. Rather than focusing on adaptation options addressing specific dimensions of climate change, more attention is being paid to mainstreaming climate change in government policy and private sector activities (Sietz *et al.*, 2011). Rarely will adaptation options be designed to address climate risks or opportunities alone (IPCC, 2007B). Instead, changes and innovations will often be undertaken with other goals (such as profit or poverty reduction) in mind, while also achieving climate-related co-benefits. Defining a specific set of climate adaptation options may be difficult. Moreover, a direct climate signal (such as a recorded change in precipitation, for instance) alone is rarely the sole reason for an adaptation. Such signals, however uncertain or clear, need to be interpreted and weighed against other cultural, economic, political or social signals that may encourage change. Indirect signals from regulators or customers may be a stronger signal to adapting agents that observed climate itself (Berkhout *et al.*, 2006).

Against this background, the enactment of adaptation options is seen as taking place in a social, cultural and institutional context. Moser *et al.* (2008: 647) argue that adaptation can be seen, '…as a sequential process by which changes occur through a network of actors, stimulated by the actions of innovation pioneers or early adopters, who pass on their experiences to others.' Adaptation options and adaptation action are therefore context-specific. For assessment, Moser *et al*. (2008) provide a summary of factors to be considered:

1) Examine the range of available *technological options* for adaptation that would be considered in response to a perceived climate-related stress;
2) Evaluate the availability of *resources* with particular attention paid to equitable distribution across the population;
3) Explore the structure and functionality of *critical institutions* to understand the allocation of decision-making authority, institutional flexibility and the decision criteria that would be employed;
4) Assess the *human and social capital*, including the distribution of educational achievement, differential access to personal security and robust property rights;
5) Document the system's (and individuals') access to *risk-spreading processes* (both formal and informal);
6) Assess decision-makers' ability to *manage information*, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers themselves; and
7) Calibrate the public's *perceived understanding* of the stresses and the population's readiness to engage in implementing necessary adaptation measures.' (p 647)

A number of conclusions flow from this analysis. First, there are frequently a wide range of adaptation options theoretically available to adapting agents. Second, there will be divergent perceptions and opinions about these options, influenced by the range of attitudes that exist about the goals of adaptation, risk and uncertainty, costs and benefits and so on. Third, whether adaptation options are implemented will depend on the capabilities of adapting agents, on the distribution of power and resources and on governance. And fourth, many of the gains in reduced vulnerability, enhanced resilience or greater welfare arising from *climate adaptations* will be co-benefits generated as a result of changes and innovations driven by other factors. One of the main contributions of recent research on adaptation has been to suggest that adaptation options, at least the majority of those that might be expected over the short-term, are often ambiguous, contested and embedded in specific contexts.

The literature on costs and benefits of adaptation suggest that the integrated assessment models, which are key tools to assess climate change policies, have begun to address adaptation, either by including it implicitly in damage cost estimates, or by making it an explicit control variable. Under some conditions, better modeling of adaptation costs and benefits could have important implications for defining mitigation targets (Patt et al, 2010). For example, the results of the AD-DICE model suggests that about one-third of the damages from climate change would in an optimal case be eliminated by adaptation. As a result, adaptation generates the majority of damage cost reduction before 2100, while mitigation generates the majority of damage cost reduction after 2100. The model indicates that the optimal mitigation effort with optimal adaptation is about one quarter less than the optimal mitigation effort in the absence of any adaptation: for instance, in 2050—under the DICE assumptions—it would be optimal to reduce emissions in 2050 by about 22% from their business-as-usual level if there is no adaptation, whereas with optimal adaptation it is optimal to reduce emissions by only 16%. The assumption of perfectly functioning markets, and a global adaptation function, may be a limitation of their model (de Bruin *et al*. 2009).

Most of the contemporary concern about extreme climate swings is associated with anthropogenic global warming. Growing apprehension that mitigation cannot keep global warming below dangerous levels (Parry *et al*., 2009; Schneider, 2009) leads logically to calls for more attention to adaptation and to potential geo-engineering interventions at least to ameliorate the overshoot likely before mitigation can take hold, and "just in case" we face climate emergencies (Schneider, 2008; The Royal Society, 2009). Both adaptation and geo-engineering would need information and decision support (National Research Council, 2009), such as systems that could detect and warn about impending severe changes in the earth's climate system (e.g., ice sheet collapse, regional flips to more arid climates, etc.) with some skill and at some policy relevant lead time (Lenton *et al*., 2008). Adaptation can include both short- and long-term decisions that can be implemented at different rates depending on expected rates and magnitudes of climate change.

16.3.2. Opportunities Arising from Adaptation

16.3.2.1. Possible Opportunities Arising from Adaptation

Although much research has viewed adaptation at a response to a new hazard or risk, there has also been a growing appreciation that climate change offers opportunities to actors in some places and for certain periods. Opportunities arise in two main ways – through improved adaptedness to current climates; and through exploiting new opportunities that arise as a result of changing climate, including the provision of climate adaptation goods and services:

- Stimulating adaptation to current climate variability: While it is generally assumed that physical, ecological and social systems are well-adapted to current climatic conditions; this is frequently not the case (Smit, 1993; Heyd and Brooks, 2009; Dugmore *et al*., 2009). Changes in observed climate, as well as the societal discussion about it, may lead currently maladapted actors and organisations to make changes that bring net benefits.
  – Reducing losses to current climate variability: Many ecological, economic and social processes are subject to some climatic pressure. For instance, there is a risk of failure of a fruit crop as a result of frost (Rochette *et al*., 2004; Quamme *et al*., 2010). Climatic change may lead to a change in the pattern of such pressures, leading to a reduced vulnerability. As in this case, climate change may lead autonomously to a net increase in welfare, even absent adaptation.
- Exploiting new opportunities as a result of current and future climate change: Climatic change may offer opportunities for new activities. For instance, the absence of summer sea ice in the Arctic as a result of warming may open-up new sea routes (Wilson *et al*. 2004), or make the exploitation of natural resources viable (Brigham, 2007). Warmer temperatures will create opportunities of crop production in colder regions where planting is currently temperature- or moisture-limited (Lobell *et al*. 2008). Increase in forest biomass as a result of higher concentrations of carbon dioxide may improve forestry productivity (Boisvenue and Running, 2006).
  – Provision of climate adaptation goods and services: Since adaptation will generally require additional investment and effort. It therefore represents an economic opportunity for some producers of goods and services. For example, the market for snow machines will be influenced by growing concerns about snow cover in more marginal ski resorts (Scott *et al*., 2006). In Arizona's high elevation, low latitude ski resorts by 2050, temperatures will likely exceed technical thresholds in the shoulder seasons meaning that in years when natural snowfalls are poor the ski season may be curtailed. Higher elevation regions will see new opportunities as a result of snow resort shifts (Bark *et al*., 2009). Likewise, new and innovative railway track and drainage systems may develop a market for dealing with track buckling caused by higher summer temperatures (Barke *et al*., 2009). The Stern Review suggested that huge market opportunities existed for new infrastructure and buildings resilient to climate change in OECD countries, with a potential value of between £9.5bn and £94.8bn per year (Stern, 2006). New services related to climate prediction and insurance are also likely to develop. Rising damage caused by climate change could provide new markets for innovative insurance products. Insurance can play an important role managing risks associated with climate-related damages (Kelkar *et al*., 2009; Botzen *et al*., 2009; Robert *et al*., 2008).

16.3.2.2. Opportunities for Whom?

While opportunities arising from climate change can be discussed in general terms, and there are surveys of adaptation options (Tompkins *et al*., 2009), no comprehensive analysis of opportunities has been conducted. Nor do integrated assessment models take fully into account the range of potential adaptation opportunities and their economic and social benefits (Patt *et al*. 2010). It is clear that the distribution of opportunities arising as a result of climatic change is highly uneven – geographically, socially and temporally:

- *Geographical*: Climate change is non-uniform in its impacts across world regions and at more local scales. This relates to the nature and speed at which climatic changes occur, and whether these are perceived as risks or opportunities by social actors. In some regions or sectors perceived benefits will outweigh perceived risks, although it is likely that these will continue to exist side-by-side in all places.

- *Socio-economic*: It is well-established that environmental risks are disproportionately experienced by marginal and vulnerable social groups and regions (Brouwer *et al*., 2007; Mearns and Norton, 2010). These groups will also have fewer resources and capabilities to exploit climate change-related opportunities as they emerge. Indeed, whether a change in climate is viewed as an opportunity or a threat may be socially-determined. For example, a farmer able to invest in developing a vineyard in response to warming at a cooler latitude will have a different perception than a less well-capitalised neighbour who decides to continue to farm maize (Jones, 2007).
- *Temporal*: If climates everywhere are now in a transitional state, it follows that the pattern of risks and opportunities that emerge as a result of climate change will change through time. A degree of warming which represents an opportunity in the short-run may over the longer term (New *et al*., 2011).

16.3.3. Opportunities for Adaptation as Part of Decision-Making Processes

Aaheim *et al*. (2008) argue for seven objectives for public policy action in relation to climate change adaptation: to inform the potentially vulnerable; to assist in the provision of disaster relief; to provide incentives for and enable adaptation; to mainstream climate-proofing of public policy; to plan and regulate long-term infrastructural assets to reduce future vulnerabilities; to regulate adaptation 'spillovers'; and to compensate for the unequal distribution of climate impacts. In all these roles, Governments can play a significant role in both enabling adaptation opportunities to be exploited:

1) *Information, knowledge and learning*: Governments have played a major role in sponsoring climate science and in the provision of tools such as global, regional and national climate scenarios.
2) *Early-warning and disaster relief*: Most governments have in place plans, organisations and resources to alert people to weather-related disasters and to cope with the consequences, at home and abroad.
3) *Facilitating adaptation in the market*: There are strong 'public good' arguments for investing in scientific and technological resources and capabilities that may be widely adopted in response to climate change. Beyond this, Governments can help create markets and innovative capabilities in firms to encourage adaptive action, including the removal of perverse incentives leading to maladaptation.
4) *Mainstreaming climate-proofing*: Large areas of public policy applies to climate-vulnerable sectors, either because they are collective goods (like nature conservation) or because the state has a clear role through regulation or ownership (like water). In these sectors government will play part of the role in enabling or encouraging adaptation.
5) *Infrastructure planning and development*: Water, transport and energy infrastructures are likely to be influenced by changing climate, as is the distribution of settlements, especially in coastal and fluvial flood plains. Modification of infrastructures and of spatial plans in response climate impacts is another area in which governments will play a major role.
6) *Regulating adaptation spillovers*: Unregulated, it is likely that the most vulnerable social groups will end up bearing many of the new social and economic risks that arise as a result of climate change.
7) *Compensating for the unequal distribution of climate impacts*: The notion of compensation is by now well-entrenched in public health and environmental policy. Where the cause of damage can be well-defined, compensation can be dealt with between individuals, but where it cannot be clearly established, governments need to play a role.

16.3.3.1. Adaptation in Existing Policies and Measures

The United Nations Framework Convention on Climate Change (UNFCCC) has adapted a series decisions to enhance adaptation to climate change, including the Bali Action Plan (2007) which prioritized adaptation to climate change action as one of its five building blocks (UNFCCC, 2007) and the Cancun Agreement (2010) in which 'Enhanced action on adaptation' is an important component (UNFCCC, 2010). Regional policy strategies are also being developed. The European Commission issued a Green Paper (2007) and a White Paper (2009) setting out a European strategy for climate adaptation. Asian ministers adopted the Incheon Regional Roadmap and Action Plan on Disaster Risk Reduction through Climate Change Adaptation in October 2010. At the national level, some 45 least developed countries have developed National Adaptation Programmes of Action (NAPAs). NAPAs provide a process for LDCs to identify priority activities with regard to adaptation to climate change (UNFCCC, 2011). Several European countries have also developed national climate adaptation strategies (Biesbroek *et al.*, 2010).

In some countries, national strategies have been formulated and mainstreamed into a national development plan. China's 'National Climate Change Programme' and provincial climate change programmes were formulated and implemented in 31 provinces. Prioritized adaptation actions were the distribution of agricultural production, infrastructure and planning of engineering projects. Mainstreaming of adaptation to climate change is occurring in a limited fashion as part of the regular risk management activities of national and sectoral planners. This requires special attention in the design of institutional mechanisms for coordination and exchange of good practice, particularly within countries. Transboundary and regional coordination of adaptation action has received less attention. Most climate change actions and adaptation plans are at the national level, although impacts of climate change cut across national boundaries. Meaningful integration of a range of climate risks, from flood control to dry season flows to glacial lake hazards, would require greater coordination on data collection, monitoring and policies at the regional level. Finally, operational guidance on comprehensive climate risk management in development is needed to facilitate policy coherence, allow for joint building of experience, and promote the sharing of tools and experiences within and among governments and development cooperation agencies (Agrawala & Aalst, 2008).

16.3.3.2. Options for Intervention (Adaptation Deficit, Development Deficit, Knowledge Deficit)

To be elaborated:

The failure of current adaptation responses to keep pace with development is called the adaptation deficit (Burton, 2004).

Options for intervention:

- To integrate climate change risks into development activities.
- The need to mainstream adaptation to climate change into development planning is increasingly recognized (Klein *et al.*, 2007).
- Several opportunities exist for the more effective integration of climate change adaptation within development activities
  - Making climate change information more useful and easier to use
  - Focusing more on implementing climate change and development strategies, and
  - Increasing coordination between development and climate change policies (Shardul & Maarten, 2008).
- To build adaptive capacity to climate change
- Adaptive capacity is the ability to respond to climate changes and then to initiate responses to the climate changes.
- Adaptive capacity is limited due to the capitals, institutions, knowledge and information, decision making and governance, and innovation capacity deficit.
- Options to overcome the limitations of adaptive capacity.
- To promote international cooperation
- Adaptation deficit can be more effectively addressed by combining the Climate Convention work with the development process and mainstreaming climate risk (Burton, 2004).

16.3.3.3. Resource Planning and Adaptation Linkages

The adaptive capacity to changing climate is based on its natural resource endowment and associated economic, social, cultural and political conditions (Wall and Smit, 2005). Rational resources planning can enhance the climate change adaptation capacity. Adaptation also can promote the conservation of natural resource and its optimized utilization at the regional and national level. Societies and communities dependent on natural resources need to enhance their capacity to manage their natural resources and adapt to the impacts of future climate change, particularly when such impacts could lie outside their experienced coping range (Tompkins & Adger, 2004). Integration is a key feature for practicing and promoting sustainable resource planning and for developing climate change adaptation policy (Wall and Smit, 2005), which engage to develop resource management strategies as a means of building a constituency for resource problems associated with climate change (Tompkins & Adger, 2003).

Climate change is explicitly taken into account in water resource management plans for ensuring sustainable water supplies in future. The climate change impacts and risk was considered into water resources and infrastructure planning and management process for adapt to the challenges of future climate change (EBNCCA, 2011). The new framework for implementing Water Demand Management was effective to adapt future climate change for achieving long term trade-offs between ecological and socio-economic water needs in middle reaches of Yellow River (Wang *et al*., 2010). Broward County (Florida, USA) has integrated the water resources and climate adaptation planning, formulating a coordinated strategy to promote sustainable water management that is mindful of existing and anticipated pressures and the County's overarching environmental goals (ISC, 2010).

The role of land use planning was addressing disaster management, long-term migration shifts, heat and pollution, endangered species survival and water conservation (Kaswan, 2011), thus land use planning must be related to climate change impact and its adaptation. The community-based management enhances adaptive capacity by building networks that are important for coping with extreme events and by retaining the resilience of the underpinning resources and ecological systems in Trinidad and Tobago (Tompkins & Adger, 2004). The specific land use planning strategies to address climate change can be incorporated into national development plans for reducing their vulnerability (Lewsey *et al*., 2004). Effectiveness and cost-efficiencies in adaptation may also be influenced by the timing of resource management and planning (Joyce *et al*., 2009).

16.4. Adaptation Resources and Constraints

16.4.1. Adaptive Capacity and Constraints

Adaptation to climate change is a complex social process, which can be deconstructed into a range of operational phases and activities (Moser and Ekstrom, 2010; Preston *et al*., 2011). For example, Moser and Ekstrom (2010) identify three critical phases in adaptation: understanding, planning and managing (Figure 16-3). Each of these is associated with multiple activities that contribute to adaptation outcomes. These phases and activities also present potential opportunities for factors exogenous or endogenous to the process to constrain adaptation through a variety of mechanisms (Adger *et al*., 2007; Howden *et al*., 2007; Repetto, 2008; Tribbia and Moser, 2008; Adger *et al*., 2009a; Bryan *et al*., 2009; Smith *et al*., 2009; Moser and Ekstrom, 2010; Nielsen and Reenberg, 2010; Huang *et al*., 2011; Measham *et al*., 2011). Such constraints can be viewed as factors that reduce the capacity of institutions, regions, sectors and/or ecosystems to adapt to the adverse consequences or opportunities posed by climate change (Adger *et al*., 2009a).

[INSERT FIGURE 16-3 HERE
Figure 16-3: Phases and activities associated with the adaptation process (Moser and Ekstrom, 2010).]

The IPCC AR4 noted that adaptive capacity is comprised of multiple factors including availability and entitlements to resources (e.g., finance, technology, knowledge), institutional arrangements and policies, social and cultural characteristics, as well as cognitive factors (Adger *et al*., 2007). Constraints on these determinants of adaptive capacity can reduce the adaptation options that are available, increase the costs or time horizon for the implementation of adaptation options, and/or reduce the capacity of organizations to capitalize on opportunities posed by climate change. The differential presence and absence of constraints accounts for the differential adaptive capacity among nations, regions, sectors and communities (see Section 16.4.3). Some constraints are generic and common to adaptation processes across regions and/or sectors. Others are context-specific and may only become apparent through critical examination of adaption processes *in situ*. Furthermore, different constraints may operate over different time scales and their influence may change suddenly in response to unforeseen events (see Section 16.4.4). To the extent that one or more constraints prevent institutions from achieving adaptation objectives, constraints can become limits to adaptation (see Section 16.5).

Since the IPCC AR4, attention to adaptation constraints and their influence on adaptive capacity has increased through a number of case studies focusing on particular sectoral or regional contexts. This has resulted in a richer understanding of the determinants of adaptive capacity and the range of opportunities for facilitating adaptation. This includes theoretical understanding of the diversity of constraints that may impede adaptation and how they interact as well as practical demonstrations of such constraints in operation in specific contexts (Moser and Ekstrom, 2010). Despite the expansion of interest regarding adaptation constraints, much of the recent literature seeks to identify constraints as a means of increasing adaptive capacity and the effectiveness of adaptation (Smith *et al.*, 2009). In this context, the removal of potential constraints on adaptation is fundamental to adaptation efforts and should be considered in conjunction with traditional adaptation options involving discrete policies and measures that target societal and/or ecological vulnerabilities (Adger *et al.*, 2009a; Smith *et al.*, 2009; Moser and Ekstrom, 2010).

16.4.2. Types and Sources of Constraints

16.4.2.1. Conceptual Frameworks of Adaptation

Adaptation processes are socially constructed and are therefore influenced by the manner in which individuals and institutions perceive climate change risks and the conceptual frameworks employed to structure decision-making regarding adaptation. Although the IPCC AR4 identified risk perception and other aspects of human cognition as a potential constraint on adaptation, the literature on this topic has expanded in recent years. In particular, recent studies have demonstrated the complexity associated with identifying relationships between risk perception and adaptive behaviours. For example, Wolf *et al.* (2010) find that elderly individuals in the UK generally have low perceptions of their own vulnerability to heat waves, particularly when part of a social network, a phenomenon that may ultimately prove maladaptive. Whitmarsh (2008) finds that perceptions of climate risk were mediated indirectly through individual, environmental values rather than through overt experience with climate impacts. Meanwhile, van der Berg *et al.* (2010) note that drivers of climate adaptation in nine Dutch municipalities had little to do with risk perception (e.g., past experience or anticipation of future changes in climate), but rather was driven by local leadership and normative motivations to take action. While this suggests an important role for top down institutional leadership on adaptation (see also Tompkins *et al.*, 2010), perceptions of risk and the importance of adaptation may differ between institutions and the stakeholders they represent (Patt and Schröter, 2008).

Cognition influences not only individuals' perceptions of risk but also how they frame adaptation processes. For example, Pielke (2005) notes that institutional definitions of climate change as a strictly anthropogenic change in climate versus a change due to either natural or anthropogenic forcings have had significant implications for adaptation policy and the eligibility of adaptation efforts to receive funding through mechanisms such as the Global Environment Facility (GEF). Fünfgeld and McEvoy (2011) and Preston *et al.* (2011) present different typologies of assessment methods to inform adaptation planning, noting that different methods are associated with their own strengths and weaknesses. Similarly, Füssel and Klein (2006) note that different assessment frameworks have evolved over time resulting in greater emphasis on non-climatic determinants of vulnerability including adaptive capacity (see also Jones and Preston, 2011). Despite this evolution of assessment practice, there is still little understanding how different assessment approaches or framings perform in different contexts with respect to facilitating adaptation (Preston *et al.*, 2011). Such challenges are prompting research into the characteristics, evolution and implications of different framings of adaptation (McGray *et al.*, 2007; McEvoy *et al.*, 2010; Fünfgeld and McEvoy, 2011) as well as efforts to map relations between adaptation and associated concepts like vulnerability and resilience (Cork, 2010; Gallopin, 2006; Miller *et al.*, 2010; O'Brien *et al.*, 2007; Young, 2009) These efforts have largely focused on the dominant distinction between adaptation as a function of future hazard and risk versus present day vulnerability (Fünfgeld and McEvoy, 2011; Table 16-3). Concerns have been raised that framing adaptation in terms of available or dominant tools, paradigms and institutions such as climatic predictions, risk management and economic development, may obfuscate the need for and desirability of alternative approaches (Eriksen and Brown, 2011; Eriksen *et al.*, 2011; Hulme *et al.*, 2009; O'Brien *et al.*, 2007; Pelling, 2011). Perceptions of what the goal of adaptation is, what barriers obstruct its realization, and what barriers may be inadvertently created by certain adaptation efforts, are also products of how adaptation is framed (Fünfgeld and McEvoy, 2011).

[INSERT TABLE 16-3 HERE
Table 16-3: Strengths and limitations of three popular framings of climate change adaptation assessment (based on information in Fünfgeld and McEvoy, 2011).]

16.4.2.2. Adaptation Resources and Entitlements

Knowledge and information

The generation and dissemination of knowledge and information regarding climate change and adaptive responses are an important component of adaptation processes. The various types of information most frequently considered in adaptation include the following: a) information regarding future biophysical and socioeconomic states and associated uncertainties (Keller *et al*., 2008; Moss *et al*., 2010; Wilby *et al*., 2009); b) information regarding adaptation options and their associated costs and benefits (Prato, 2008; de Bruin *et al*., 2009; Patt *et al*., 2010); and c) information regarding the various constraints on, or limits to, the implementation of those options and how they can be ameliorated (Mitchell *et al*., 2006; Moser, 2009; Smith *et al*., 2009; Moser and Ekstrom, 2010; Conway and Schipper, 2011). Of these, research has traditionally targeted the first need through climate change science, scenario development and assessments of vulnerability, impacts and risk. However, the need for information regarding adaptation options, costs and benefits has become more prominent in recent years (de Bruin *et al*., 2009; Parry *et al*., 2009; Patt *et al*., 2010; World Bank, 2010; Chapter 17), including greater attention to learning from traditional knowledge (Nyong *et al*., 2007; Barnett, 2010; Ford *et al*., 2007). In contrast, the provision of information regarding how to overcome constraints on adaptation is relatively limited.

Despite the emphasis placed on knowledge and information in adaptation processes, the adaptation literature reflects different perspectives on the ultimate role of knowledge and information in facilitating adaptation. On one hand, adaptation practitioners and stakeholders continue to identify a deficit of information as a major constraint on adaptation (Adger *et al*., 2009a; Jones and Preston, 2011; Preston *et al*., 2011). For example, surveys conducted in the United States and Australia of stakeholders in government and non-governmental organizations indicate that lack of information is an important barrier to adaptation (Jantarasami *et al*., 2010; Gardner, 2010; see also Tribbia and Moser, 2008; Ford *et al*., 2011). Similarly, Preston *et al*. (2011) note that intelligence gathering to address knowledge gaps features prominently in adaptation planning in the developed world. Information constraints are also commonly cited in the developing world as evidenced by case studies from Ethiopia and South Africa (Bryan *et al*., 2009; Deressa *et al*., 2009), and the pursuit of adaptation has been linked to education and awareness of climate change among actors (Deressa *et al*., 2011).

Such demand for information, particularly with respect to climate variability and change, is a key factor underpinning efforts at various scales to develop more robust climate services (Trenberth, 2008; Scott *et al*., 2011; Sivakumar *et al*., 2011; WMO, 2011). Nevertheless, the Fourth Assessment Report concluded that knowledge in itself is not sufficient to drive adaptive responses. More recently, Costa-Font *et al*. (2009) find that the social optimism bias tends to be higher for risks, such as climate change, that are well-publicized compared with less familiar risks. Preston *et al*. (2009) also find that local government stakeholders self-reported ability to manage climate risks was greater for those hazards for which they have immediate experience and/or responsibility. This suggests that expanding of awareness through information dissemination does not necessarily lead to greater perceptions of risk or demand for action. In particular, recent literature has questioned the extent to which uncertainty and/or lack of information about future climate change is a constraint on adaptation (Hulme *et al*., 2009; Dessai *et al*., 2009; Wilby and Dessai, 2010). Other authors have also questioned the utility of commonly used vulnerability metrics and assessments for informing adaptation decision-making (Barnett *et al*., 2009; Preston *et al*., 2009, 2011; Hinkel, 2010). Hence, while there is clear evidence linking knowledge and information to adaptation, the extent to which knowledge acts to constrain or enable adaptation is ultimately dependent upon how that knowledge is generated, shared and used to achieve desired adaptation outcomes (Patt *et al*., 2007; Nelson *et al*., 2008; Tribbia and Moser, 2008; Moser, 2010).

Natural resources

Many of the adaptation options available for given sectors or regions are dependent upon the pool of natural resources that can be harnessed to facilitate adaptation. However, natural resources and systems are under pressure from multiple sources in many global regions, often in association with the legacy of past environmental management decision-making (MEA, 2005). Such constraints on natural resource supply as well as quality can significantly constrain the adaptation measures that are available to individual, communities and organizations as well the cost and effectiveness of those measures (Barnett and Adger, 2007). This constraint is particularly relevant in developing nations and small island states where livelihoods are particularly dependent upon natural resources and sensitive to their disruption. Since the IPCC AR4, a number of livelihood analyses in different regional and sectoral contexts have explored the role of access to natural capital and resources in influencing vulnerability and the capacity to adapt to climate change (Paavola, 2008; Thornton *et al*., 2008; Iwasaki *et al*., 2009; Badjeck *et al*., 2010; Nelson *et al*., 2010a,b). A particular focus of natural resource availability in the literature is climate change and risk to water resource security. For example, demand for fresh water for human consumption is increasingly encroaching upon the sustainable yield of surface and groundwater systems in a number of global regions (Shah, 2009). As a consequence, such systems have reduced flexibility to cope with reductions in water supply due to short-term climate variability and/or long-term climate change. This in turn influences the effective portfolio of adaptation actions that can be implemented to ensure a secure water supply and, subsequently, agriculture and food security (Hanjra and Qureshi, 2010).

The degradation of natural resource quality is another source of constraints on adaptation to climate change (Côté and Darling, 2010). A number of studies have identified pathways by which non-climatic stresses to ecological systems can reduce their resilience to climate change, with particular emphasis in the literature on coral reefs and marine ecosystems, tropical forests and coastal wetlands (Malhi *et al*., 2007; Diaz and Rosenberg, 2008; Kapos and Miles, 2008; Afreen *et al*., 2011). Such ecological degradation also influences the goods and services provided by those systems to human societies (Nkem et al, 2010; Tobey *et al*., 2010). For example, degradation of coastal wetlands and coral reef systems may reduce their capacity to buffer coastal systems from the effects of tropical cyclones (Das and Vincent, 2009; Tobey *et al*., 2010; Gedan *et al*., 2011; Keryn *et al*., 2011), although questions have been raised regarding the effectiveness of this as a management strategy (Chatenoux and Peduzzi 2007; Kerr and Baird 2007; Feagin 2008, Kerr *et al*. 2009). Meanwhile, soil degradation and desertification reduce crop yields and the resilience of agricultural and pastoral livelihoods to climate stress (Iglesias *et al*., 2011; Lal, 2011). These consequences of degraded natural capital reduce coping capacity and resilience and thus are likely to increase the demand for adaptation as the climate changes. Meanwhile, as ecosystem goods and services represent a low cost pathway for coping with climate stress, loss of such services may reduce flexibility in the choice of adaptation measures and potentially increasing their cost.

Financial resources

Constraints on the capacity to finance priority adaptation measures is widely recognized as a potential impediment to adaptation, yet one which manifests differently across a range of geopolitical scales. At the international scale, a number of mechanisms have been implemented for financing adaptation in developing nations including the UNFCCC's Adaptation Fund, as well as the Global Environment Facility Trust Fund, Least Developed Countries Fund and the Special Climate Change Fund. However, the demand for adaptation finance indicated by recent estimates of the global costs of adaptation is significantly larger than the current availability of resources represented through these funds (Flåm and Skjærseth, 2009; Hof *et al*., 2009). Furthermore, the challenge of developing a framework for the equitable and effective allocation of adaptation funds to developing nations is non-trivial (Barr *et al*., 2010; Smith *et al*., 2009). Alternative funding mechanisms such as overseas development assistance (ODI) have been discussed as ways of subsidizing the adaptation funds, yet the reallocation of ODI may undermine adaptive capacity by diverting resources away from programs and projects targeting development goals (Ayers and Huq, 2009). Although attempts such as the Fast Start Mechanism emerged from the Conference of the Parties 15 to help accelerate the delivery of near-term adaptation finance, it is currently unclear what mechanisms will be developed for ensuring financial resources are available over the long-term to meet adaptation demands.

While significant attention has been given to discussions of international adaptation finance to support adaptation in developing nations, a range of finance challenges have been identified in other regions and scales. Investigations of farming communities in Africa, for example, have identified finance as a key determinant of vulnerability and adaptive capacity of farmers to climate variability and change (Nhemachena and Hassan, 2007; Hassan and Nhemachena, 2008; Deressa *et al*., 2009, 2011). Yet, such case studies often examine the issue of finance as one component of a broader livelihoods framework (Paavola, 2008; Osbahr *et al*., 2010). Meanwhile, despite traditional assumptions regarding the high adaptive capacity of developed nations, institutions in such nations may still face challenges in funding adaptation measures, although financial constraints are often discussed in the broader context of resource limitations (Jantarasami *et al*., 2010; Moser and Ekstrom, 2010). Jantarasami *et al*. (2010) interviewed staff from federal land management agencies who identified resource constraints as a key barrier to adaptation. Similarly, surveys and interviews with state and local government representatives in Australia indicate that the costs of investigating and responding to climate change are perceived to be significant constraints on adaptation at these levels of governance (Gardner *et al*., 2010; Smith *et al*., 2009). In a review of adaptation plans from developed nations Preston *et al*. (2011) found that such plans generally neglected consideration for the financial capital needed to implement priority adaptation actions.

A number of mechanisms exist that may exacerbate the financial constraints placed on adaptation. First, adaptation demand is likely to be influenced by the demand for and effectiveness of international greenhouse gas mitigation efforts (Tol, 2007; Hof *et al*., 2009; Yohe and Strzepek, 2010). Hence, the greater the rate and magnitude of climate change (Section 16.4.2.5), the more costly adaptation efforts are likely (Chapter 17). Hence, the burden of financing adaptation is directly linked to mitigation efforts (Chapter 20). Second, Adger *et al*. (2009) and Moser and Ekstrom (2010) identify a range of potential barriers to adaptation and Moser and Ekstrom (2010) note that such barriers are likely to make adaptation less efficient and more costly. Therefore, the constraints placed on adaptation through process are linked to other forms of resources that influence adaptive capacity.

Technology and infrastructure

The adaptation literature recognizes technology as a critical driver of and constraint on both adaptation to climate change as well as economic development and sustainability more broadly (UNFCCC, 2006; Adger *et al*., 2007). Adaptation technologies include both physical capital such as infrastructure, facilities and equipment as well as management practices, techniques and design principles. The IPCC AR4 noted the role of technology in contributing to spatial and temporal heterogeneity in adaptive capacity and the potential for technology to constrain adaptation or create opportunities (Adger *et al*., 2007). Meanwhile, the economics literature indicates that impacts to existing infrastructure and the needs for new infrastructure to manage emerging climate risks dominate adaptation costs (see Chapter 17, World Bank, 2006; Nicholls *et al*., 2007; UNDP, 2007; UNFCCC, 2007; Parry *et al*., 2009). Hence, technology has been identified as one factor associated with the so called ‘adaptation deficit’ of particular regions and sectors (Burton 2004, 2005; Burton and May 2004). For example, technologies for water resource management in many developing nations are inadequate to ensure a reliable and safe drinking water supply, which reduces their capacity to manage future impacts to water resources associated with climate change.

Key considerations with respect to technology and infrastructure include a) availability; b) access (including the capacity to finance, operate and maintain); c) acceptability to users and affected stakeholders; and d) effectiveness in managing climate risk (Adger *et al*., 2007; Dryden-Cripton *et al*., 2007; van Aalst *et al*. 2008). The adaptation literature largely explores these issues in the context of specific sectors, particularly agriculture, water resources management and coastal management (Howden *et al*., 2007; Bates *et al*., 2008; van Koningsveld *et al*., 2008; Parry *et al*., 2009; Zhu *et al*., 2010). For example, Howden *et al*. (2007) note the importance of technology options for facilitating adaptation including applications of existing management strategies as well as introduction of innovative solutions such as bio- and nanotechnology (see also Fleischer *et al*., 2011; Hillie and Hlophe, 2007; Bates *et al*., 2008). Similarly, a range of studies from Africa have explored how different factors drive awareness, uptake and use of adaptation technologies for agriculture (Nhemachena and Hassan, 2007; Hassan and Nhemachena, 2008; Deressa *et al*., 2009, 2011). Meanwhile, Nicholls (2007) and van Koningsveld *et al*. (2008) note the range of technologies that have been deployed for managing coasts and sea-level rise. Yet, while such literature identifies adaptation technologies and in some cases the costs of their implementation, quantitative understanding of the extent to which technology will enhance adaptive capacity or reduce climate impacts is limited (Piao *et al*., 2010). Shen *et al*. (2011) model water resources in response to social, economic and technological drivers and find that the sustainability of regional and global water resources is influenced by the diffusion of water-saving technologies such as recycling.

Hence, the most significant constraint of technology on adaptation is impediments to access, uptake and use of technologies. There are critical interactions among risk perception, knowledge, finance and governance in establishing the social context for adaptation technologies (Dryden-Cripton *et al*., 2007; Smith *et al*., 2009; Shen *et al*., 2011). For example, advanced technologies or large-scale infrastructure development tend to carry a higher cost than the application of existing technologies and thus may encounter greater disincentives for their application. In addition, new technologies may be associated with perceptions of risk that slow the rate of their development and diffusion (Nisbet and Scheufele, 2009; Satterfield *et al*., 2009). For example, public opposition has been reported to coastal management technologies and practices (Hayward *et al*., 2008; Zhu *et al*., 2010), biotechnology for agriculture (Nisbet and Scheufele, 2009), and a range of water resource augmentation strategies from reuse to desalination (Hartley, 2006; Dolcinar *et al*., 2011). Such challenges highlight the roles of uncertainty, risk perception and normative preferences in driving the selection and application of adaptation technologies and suggest portfolios of adaptation options may need to be considered in order to build consensus around options that are effective and equitable.

Human resources

The effectiveness societal efforts to adaptation to climate change are dependent upon the humans who are the primary agents of change with respect to adaptation. Hence, human resources provide the foundation for intelligence gathering, the uptake and use of technology, as well as leadership regarding the prioritization of adaptation policies and measures and their implementation. Although the IPCC AR4 and subsequent adaptation literature identify human resources as one of the factors influencing adaptive capacity (Adger *et al*., 2007), there has been little attention given specifically to human resources as a constraint on adaptation by adaptation researchers. Rather the literature mentions human resources in two principle contexts. First, it highlights the linkages between the development of human resources and adaptive capacity more broadly. For example, Barnett (2001) discusses the role of developing more robust administrative systems in the South Pacific for enhancing human resources to manage environmental risks such as climate change. More recently, Ebi and Semenza (2008) treat human resources as part of the portfolio of resources that can be harnessed to facilitate adaptation in the public health arena. Recent years have therefore seen the emergence of institutions to build human resources in the climate change arena, including expanded higher education opportunities to build climate expertise as well as professional societies (Murphy *et al*. 2009). Second, the literature highlights the finite nature of human resources as a need to prioritize adaptation efforts including the extent of engagement in participatory processes (van Aalst *et al*., 2008) as well as the selection of adaptation actions for implementation (Millar *et al*., 2007).

16.4.2.3. Institutional Arrangements and Legal Dimensions

To be elaborated:

- Organisation structures and procedures (e.g. silos, priorities, leadership)
- Governance (e.g. weak institutions; lack of coordination, regulation, transparency, defined responsibilities, structure of policies)
- Liability

16.4.2.4. Social and Cultural Dimensions

THE FOLLOWING TEXT HAS BEEN TAKEN VERBATIM FROM KEY REFERENCES AND IS AWAITING CITATION AND SYNTHESIS

Adaptation to climate variability and change is a social process, of assessing and responding to present and future impacts, planning to reduce the risk of adverse outcomes, and increasing adaptive capacity and resilience in responding to multiple stresses. Perceptions of risk, knowledge and experience are important factors at the individual and societal level in determining whether and how adaptation takes place. For instance, social barriers to adaptation are concerned with the social and cultural processes that govern how people react and adapt to climate hazard/variability/ change. Beliefs as well as social and cultural values affect the choice of adaptation responses. Social acceptability of flood levels and certain adaptation options differ across countries. For example, in the Netherlands, people live with floods and a certain level of flooding is socially accepted even in urban areas. On the other hand, an interviewee from the WWF Poland reported that in Poland, there are embankments that are built to protect agricultural land and forest from floods. Also, specific to Eastern Europe is the allocation of responsibility to the government with a demand that the government should take care of those affected by weather extremes and to help those for whom adaptation is too costly, e.g., farmers who cannot afford flood insurance. Reallocation that is frequent in China, in Europe usually faces strong local protests and is rarely used.

Gender sensitive analysis is important to ensure women's participation in long term climate change adaptation strategies, which might have been constrained due to their traditional social norms. For example, as women's participation in paid work outside home is low in South Asia, especially in Bangladesh, changes in crop, fishery, and poultry and livestock production could severely impact the livelihoods and well-being of women and their children. Given the gender differential in vulnerability, it is important to have social assessments and institutional analyses that include gender-based experiences in collective actions and support from local institutions/networks when developing inclusive strategies for increased climate resilience. A gender-sensitive analysis is also important to direct aid and plan for full and equitable recovery in the case of frequent climatic events such as floods and cyclones, whose frequency and intensity are expected to rise with climate change. Furthermore

Also, many studies concerned with the protection of agrobiodiversity are initiated and managed by local women's groups. For example, in India, women have initiated and engaged in a number of adaptation projects, which involve the revival of traditional seeds and the establishment of community seed banks. Another example, a women-led project from Sri Lanka, has been promoting the cultivation of indigenous roots and tuber crops, organic agriculture and integrated pest management, and seed bank establishment. Women's groups are also involved in ecosystem protection and restoration projects. An example comes from Senegal, where a collective of women's groups in nine villages manages mangrove nurseries and reforestation. The group has made significant contributions towards restoring the mangroves and protection of biodiversity, which has encouraged the return of wildlife.

16.4.2.5. Rates of Change

Future rates of global change will have a significant influence on the demand for and costs of adaptation and, generally, more rapid and unpredictable rates of change will pose greater constraints on adaptation than more gradual, monotonic changes. Rates of change can be categorized into two broad types: biophysical rates and socioeconomic rates.

Rates of biophysical change comprise the rapidity with which the physical climate system responds to radiative forcing from atmospheric greenhouse gases, the manner in which such changes manifest (such as potential increases in variability), and the response of the coupled physical and ecological Earth system to changes in climate. Since, the AR4, new research has confirmed the commitment of the Earth System to future warming (Lowe *et al*., 2009; Armour and Rose, 2011) and elucidated a broad range of tipping points in the Earth System, that would result in significant adverse consequences should they be exceeded (Lenton *et al*., 2008). Similarly, while the specific rate of climate change to which different ecological communities or individual species can adapt remains uncertain, there is confidence that more rapid rates of change constrain adaptation (Hoegh-Guldberg, 2008; Gilman *et al*., 2008; Allen *et al*., 2009; Lemieux *et al*., 2011; Maynard *et al*., 2008; Malhi *et al*., 2009; Thackeray *et al*., 2010), particularly in the presence of other environmental pressures (Brook *et al*., 2008). Meanwhile, a number of authors have suggested that scenarios of adaptation should begin examining a 4°C increase in global mean temperature (Parry *et al*., 2009; Stafford Smith *et al*., 2011). Recent literature also suggests that some aspects of human and ecological systems may be more sensitive to climate change than indicated in previous IPCC assessment reports (Pittock, 2006, Smith *et al*., 2009).

For human managed systems, understanding the implications of biophysical rates of change requires them to be considered in the context of socioeconomic change. Rapid socioeconomic change, including economic development and technological innovation and diffusion, can greatly enhance the opportunities available to institutions and communities to adapt to climate change (see Section 16.4.2.2). Yet rapid socioeconomic change can also pose constraints to adaptation. Globally, rates of economic losses from climate extremes are doubling approximately every decade (Munich Re, 2011) due to increasing human exposure (Pielke *et al*., 2008; Baldassarre *et al*., 2010; Bouwer, 2011). A number of global regions, and urban centers in particular, are projected to experience significant population growth in future decades (Montgomery, 2008; O'Neill *et al*., 2010; UN, 2011), suggesting such trends in disaster losses are likely to continue well into the future (Pielke, 2007). In addition, larger populations can lead to greater resource consumption, which is likely to constrain adaptation in regions that are resource-limited. Global trends toward population aging may also increase vulnerability by increasing net population sensitivity to climate extremes (O'Brien *et al*., 2008; Wolf *et al*., 2010; Bambrick *et al*., 2011). However, the extent to which population aging influences the capacity to adapt through impacts on the working aged population and revenue generation has yet to receive attention. The adaptation literature also suggests that successful adaptation will be dependent in part upon the rate at which institutions can learn to adjust to the challenges and risks posed by climate change and implement effective responses (Adger *et al*., 2009; Moser and Ekstrom, 2010; Stafford Smith *et al*., 2011).

16.4.2.6. Adaptation Metrics, Evaluation, and Monitoring

The IPCC's *Fourth Assessment Report* provided little discussion of the role of evaluation and monitoring of adaptation responses as a component of building adaptive capacity (Adger *et al*., 2007). Preston *et al*. (2011) identify three specific roles of evaluation: a) ensuring reduction in societal and ecological vulnerability; b) facilitating learning and adaptive management; and c) providing accountability for adaptation investments. Adaptation guidance, such as the guidelines for the preparation of National Adaptation Programmes of Action (UNFCCC, 2002), the United Nations Development Programme's *Adaptation Policy Framework* (Lim *et al*., 2005), and a range of climate change risk management frameworks (Jones *et al*., 2001; Willows and Connell, 2003; NZZCO, 2004a,b; AGO, 2006; US AID, 2007; World Bank, 2008) all emphasize the importance of evaluation and monitoring adaptation planning and implementation processes. It is difficult to assess, however, how well such guidance has been translated into practice.

A central challenge in developing robust monitoring and evaluation frameworks for adaptation is the existence of multiple valid points-of-view that can be used to evaluate adaptation (Gagnon-Lebrun and Agrawala, 2006; Perkins *et al*., 2007; Füssel, 2008; Smith *et al*., 2009; Ford *et al*., 2011; Preston *et al*., 2011). This challenges the selection of appropriate metrics for the monitoring and evaluation of adaptation and its contribution to vulnerability reduction (Burton and May, 2004; Gagnon-Lebrun and Agrawala, 2007; Hedger *et al*., 2008; IGES, 2008; Ford *et al*., 2011). One of the central unresolved tensions in progressing evaluation is the relative merits of targeting adaptation processes versus outcomes. Preston *et al*. (2011) suggest the evaluation of adaptation processes may be a more robust approach to evaluation, due to the challenges in attributing future outcomes to adaptation strategies and the long-time lags that may be needed to assess the performance of a particular strategy (Berkhout, 2005; Dovers and Hezri, 2010; Ford *et al*., 2011). However, processes that appear robust may not necessarily ensure desired outcomes are in fact achieved, and substantive outcomes are a well-established basis for policy analysis.

The IPCC AR4 concluded that adaptation is occurring, but on a "limited basis" (Adger *et al*., 2007). More recent evaluations of adaptation suggest this still to be the case (Wheeler *et al*., 2008; Biesbroeck *et al*., 2009; Ford *et al*. (2011); Berrang-Ford *et al*. (2011); Preston *et al*., 2011). Much of the adaptation evaluation literature focuses on the evaluation of adaptation planning and/or programs rather than specific adaptation actions for a given sector or region. Evaluation of adaptation in developing nations has largely targeted the NAPA process. Osman-Elasha and Downing (2007) summarize some lessons from NAPA processes in Eastern and Southern Africa, and a recent evaluation conducted by the Ministry for Foreign Affairs of Denmark and the Global Environment Facility have looked more comprehensively at the NAPA process and the Least Developed Country Fund (MFAD and GEF, 2009). Agrawala and van Aalst (2008) note that a range of barriers exist to the effective integration of adaptation within such development assistance through the Global Environment Facility and World Bank. In developed nations, the OECD has investigated progress on adaptation planning in the National Communications (NCs) to the UNFCCC made by Annex-I nations (Gagnon-Lebrun and Agrawala, 2006). The investigation distinguished between the process of completing impacts assessments, articulation of intentions to act and evidence of adaptation actions themselves. Biesbroeck *et al*. (2009) completed a review of national adaptations strategies of European Union member countries, which included an examination of motivating factors underlying strategy development, problem framing, science/policy linkages as well as multi-scaled governance arrangements. Wheeler (2008) analyses a selection of climate change plans that have emerged from state and local governments in the United States, and find that only a fraction include consideration for adaptation. Ford *et al*. (2011) and Berrang-Ford *et al*. (2011) note adaptation in developed nations often reflects intention to act rather than actions themselves, while Preston *et al*. (2011) note that even intended actions in adaptation plans from developed nations often represent capacity-building over vulnerability reduction. Such studies highlight the utility of evaluation and monitoring for adaptation as well as the need to continue developing evaluation and monitoring frameworks and ensure such frameworks are imbedded in adaptation policy and practice.

16.4.3. Generic and Context-Specific Constraints

16.4.3.1. Generic Constraints

Many of the adaptation constraints identified in Section 16.4.2 are common to multiple regions, sectors and communities. Internationally, awareness of and investments in climate adaptation have generally lagged those associated with greenhouse gas mitigation (Pielke *et al*., 2007; Wheeler *et al*., 2008; Smith *et al*., 2009). While this is rapidly changing, developing greater institutional understanding regarding adaptation and its role as a strategy for managing climate risk is a core challenge. The availability of and access to information (See Section 16.4.2.2) on future climate change, vulnerability and risk remains challenging for some institutions and stakeholders in both the developing and developed world (Preston and Kay, 2010), which can constrain adaptation efforts for agriculture, water resources management, coastal management and natural ecosystems (Tribbia and Moser, 2008; Campbell-Lendrum and Woodruff, 2010; Tarnoczi and Berkes, 2010; Ziervogel et al, 2010). However, other authors have been more critical of the utility of information on climate and vulnerability to adaptation decision-making (Tribbia and Moser, 2008; Dessai *et al*., 2009; Preston *et al*., 2009; Hinkel *et al*., 2011). Offsetting the adverse consequences of climate change and taking advantage of opportunities are likely to grow increasingly difficult with faster rates and/or higher magnitudes of climate change (Pittock, 2006; Joos and Sphani, 2008; Kriegler *et al*., 2008; Lenton *et al*., 2008; Lowe *et al*., 2009; Smith *et al*., 2009). In addition, the adaptation literature indicates that the costs of adapting to future climate change will be significant (see Chapter 17) for both the developed and developing world, yet financial resources are finite. The financing of adaptation policies and measures is therefore likely to constrain adaptation, necessitating reallocation of existing resources (Collier *et al*., 2008; von Braun, 2009; Mechler *et al*., 2010; Beckman, 2011), the pursuit of 'low' or 'no regrets' adaptation measures (Heltberg *et al*., 2008), and the development of innovative financing mechanisms (Müller, 2008). Increasingly, the adaptation literature is identifying institutional weaknesses and complex systems of governance as a common constraint on the timely and effective delivery of adaptation solutions (see Section 16.4.2.3 Adger *et al*., 2009a; Smith *et al*., 2009; Bisaro *et al*., 2010; Burch *et al*., 2010; Jantarasami *et al*., 2010; Pidgeon and Butler, 2011). Such weaknesses may include the existence of organizational silos, corruption, poor integration among organizations, unclear roles and responsibilities and lack of entitlements (Adger *et al*., 1999, 2009; Smith *et al*., 2009).

16.4.3.2. Context-Specific Constraints

Despite the existence of a range of cross-cutting constraints on adaptation, the manner in which generic constraints manifest is often context dependent. Therefore, one must be cautious in applying generic assumptions regarding adaptation constraints in assessments of vulnerability and adaptive capacity and the identification of contextually-appropriate adaptation responses (Adger and Barnett, 2009; Barnett and Campbell, 2009; Green *et al*., 2009; Mortreux and Barnett, 2009). The recent adaptation literature suggests significant work remains in understanding such context-specific determinants of vulnerability and adaptive capacity to climate change (Tol and Yohe, 2007; Smith *et al*., 2010; Hinkel *et al*., 2011; Preston *et al*., 2011). Certain global regions such as the Arctic are experiencing more rapid rates of climate change than others, increasing the urgency of adaptation. Meanwhile, coastal regions and communities must adapt to the specific issue of sea-level rise and coastal extremes (Rowley *et al*., 2007). Arid regions, such as the U.S. Southwest and southern Australia, have limited water resources to meet competing needs, which ultimately will constrain the timing and options needed to adapt to climate change, particularly if water resource reliability declines in the future (Seager *et al*., 2007; Chiew *et al*., 2009; Arnell *et al*., 2011). There is also significant geographic variability with respect to the distribution of human populations, rates of growth and their vulnerability to climate variability and climate change (O'Neill *et al*., 2010). Rapid population growth and wealth accumulation in areas that experience climatic extremes are likely to drive increased injury, mortality and economic losses in the future (Pielke *et al*., 2007). Yet, those regions that fail to benefit from global economic development and/or which experience significant out-migration may suffer from reduced adaptive capacity to adapt to future climate change. While the financing of adaptation will be an international challenge, mechanisms of finance vary significantly among regions and individual communities (Persson *et al*., 2009). A large diversity of specific social, cultural and institutional constraints to adaptation also appear in the literature (Adger *et al*., 2009a; Adger and Barnett, 2009; Moser and Ekstrom, 2010; Stafford Smith *et al*., 2011). Gender and religion have been identified as having specific cultural elements relevant to adaptation, and institutions vary substantially with respect to their awareness of climate change and adaptation as well as their capacity to adapt. This diversity in the capacity of human systems to adaptive to climate change is mirrored by ecological systems, for which there is increasing evidence of heterogeneous biogeographic and biophysical constraints on adaptation (Walther, 2010).

16.4.4. Constraints across Spatial and Temporal Scales

16.4.4.1. Spatial Scales

To be elaborated:

- Adaptation constraints are linked through teleconnections that cause constraints to act across space, geographic scales and systemic scales
- It may be difficult to delineate explicit geographic boundaries around adaptation constraints [challenge for 'place-based' vulnerability and adaptation]

16.4.4.2. Temporal Scales

To be elaborated:

- Individual constraints are dynamic and operate over different time scales
- The implications of individual constraints may be difficult to anticipate or project into the future (but some are harder than others) and new constraints may emerge rapidly

16.4.5. Constraints and Competing Values

To be elaborated:

- Adaptation constraints reduce the adaptation space resulting in trade-offs between adaptation options and other societal values [are all decisions represent some form of trade-off?]
- Mechanisms for reconciling conflicting values are essential for successfully achieving adaptation goals in the face of such conflicts

16.4.6. Ancillary Social and Ecological Benefits of Adaptation

16.4.6.1. Definition of Ancillary Benefits

As with policies to mitigate greenhouse gas emissions, adaptation policies and measures can generate ancillary or secondary benefits in addition to the primary benefits. Ancillary benefits can be defined as benefits that result from changes in social and ecological systems that are induced by adaptation rather than from the reduction in the direct negative effects of climate change (Figure 16-4). Improved accounting for ancillary benefits would lead to a more comprehensive assessment of the overall benefits of adaptation and identification of so called ‘no regrets’ adaptation actions.

[INSERT FIGURE 16-4 HERE
Figure 16-4: Primary and ancillary benefits of adaptation.]

16.4.6.2. Implications of Ancillary Benefits

Most of the studies on ancillary benefits of climate policy arise from greenhouse gas mitigation policies (Plambeck *et al*., 1997; Pittel and Rübbelke, 2008). However, adaptation actions can also generate ancillary benefits, especially at the local scale where the adaptation actions are implemented. Such, ancillary benefits can therefore provide important incentives for the implementation of adaptation actions that might otherwise be difficult to justify based upon consideration for the direct benefits alone. The potential ancillary benefits of adaptation actions can therefore expand the range of adaptation options that might be feasible and increase the likelihood that a given action or portfolio of actions will be viewed as ‘no regrets’ measures.

16.5. Limits to Adaptation

16.5.1. Types and Sources of Limits

16.5.1.1. Absolute Limits

Adaptation can be categorised more specifically into various types and forms: in terms of timing it can be ‘anticipatory’ or ‘reactive’, and on the level of preparation and outside intervention, it can be either ‘planned’ or ‘autonomous’(Tol *et al*., 2009). Adaptation within natural and ecological systems is reactive, while adaptation at the individual and societal levels can be both anticipatory and reactive in light of observed and expected climate.

The limits of adaptation are defined as obstacles that tend to be absolute or mutable. Ecological and physical limits comprise the natural limitations to adaptation, associated largely with the natural environment, ranging from ecosystem thresholds to geographical and geological limitations. For example, rapid sea-level and temperature rises could present critical thresholds beyond which some systems, such as mangrove and coral reef ecosystems, may not be able to adapt to changing climate conditions without radically altering their functional state and system integrity (Jones, 2010). Limits are common in physical and ecological systems in their natural state, but, in some instances, physical and ecological limits have been stretched or overcome with technological innovations (e.g., genetic modification of crops to increase heat tolerance).

Limits to adaptation often arise from biophysical constraints. For example, although climate conditions and extremes vary from location to location, exposure to natural hazards is endemic throughout the world. While it may be possible to expand the capacity of communities to cope with, say, a tropical cyclone or flood event, it is difficult to conceive of adaptive capacity being leveraged to the point of eliminating vulnerability to such hazards. Such limits may be particularly relevant to highly vulnerable communities such as those associated with low-lying small island nations – there are fundamental limits with respect to what capacity-building can do to ‘climate-proof’ such communities to the effects of sea-level rise (Preston and Smith, 2009).

Another dimension to adaptation limits is the inherent uncertainties in estimating future climate and societal change – despite the best efforts of research, ranges of uncertainty are likely to stay relatively wide. The ultimate implications of uncertainty as a limit to adaptation are inherently linked to the decision-making framework (e.g. different frameworks may have a different evidential burdens-of-proof to justify adaptation actions) which leads conveniently to a discussion of barriers. Adaptation within social systems relates to the processes people use to reduce the adverse effects of climate on their livelihood an well-being and take advantage of new opportunities provided by their changing environment (TERI, 2007).

Social barriers are made up of various processes relating to cognitive and normative restrictions that prevent individuals or groups from seeking the most appropriate forms of adaptation. Chowdhury *et al.* (1993) show how cultural norms in a number of south Asian nations increase female vulnerability to flooding, resulting in a disproportionate amount of female deaths. Local institutional restrictions prevent women from learning how to swim, as opposed to not being able to swim. In addition, women feel obliged to wear clothing that inhibits swimming and are constrained in their access to emergency warnings and cyclone shelters as a result of cultural norms, substantially increasing their vulnerability in the face of water-related hazards (Twigg, 2004). These social barriers occur not as a result of their femininity, but rather through the institutional and cultural environment that governs acceptable behaviour and entitlement towards women (Bowen and Khadgi, 2008).

Predicted future changes in climate, with consequent impacts on ecosystems and physical systems, pose significant challenges for society. Forests are expected to face significant pressure from climate change over the next century which will potentially disrupt the important ecological, economic, social and aesthetic services that forests provide to other natural systems and humankind (IPCC, 2007b; Bonan, 2008; Eastaugh, 2008). According to the World Bank, more than 1.6 billion people worldwide depend on forests for their livelihoods, the majority of whom live in extreme poverty. Of that number it is estimated that 60 million indigenous people are totally dependent on forests, 350 million are highly forest dependent, and 1.2 billion are dependent on agroforestry (The World Bank 2008a). In Africa, over two-thirds of the population of approximately one billion people, rely directly or indirectly on forests and woodlands for their livelihood, as well as medicinal plants and common pool forest resources for meeting essential fuel wood, grazing and other needs. Similar patterns of dependency are observed in the Congo Basin Forests whose over 30 million inhabitants, representing over 150 ethnic groups, depend on the forest for food, shelter and other livelihood activities (Congo Basin Forest Partnership, 2006). The vulnerability of tropical forest ecosystems to climate change represents a risk to the livelihoods of these forest-dependent communities and to the development of national economies. Additionally, the impact of natural-resource on ecosystems and communities in the Congo Basin forest of Cameroon showed that in long term the climate change would have an effect on biodiversity in the forest zone, which could lead to changes in the range of some species of plants and animals and possibly their ultimate disappearance. This in turn would have a negative effect on local communities who depend on the forest for their livelihood (Brown *et al.*,2010).

Also, the review of the literature has revealed that a forest's exposure and sensitivity to climate change will be affected by climate trends and variability, land use change and management which will affect adaptive capacity of the forests. For example, these changes will affect tree-level processes (e.g. productivity), site conditions, stand structure (e.g. density, height, basal area) and species distributions (Johnston and Williamson 2007). Forest management will need to adjust to changes in seasonal operations, changes in product (species that can be grown in an area), changes in wood supply (positive in some areas such as boreal forests of Sweden and Finland but negative in dry-tropical areas (Roberts *et al.* 2009), and changes in costs, demand, prices and benefits. Other forest values will also change such as carbon storage, nutrient cycling, wildlife habitat, biodiversity, recreation, Indigenous use and aesthetics (Johnston and Williamson, 2007) with unknown affects on adaptive capacity. Loss of biodiversity, that is diversity of genes, species and ecosystems, limits the capacity of a system to adapt.

A wide-ranging review of the available literature covering the adaptation planning resources shows that at the organization level, similar factors have been identified as limiting adaptation: lack of knowledge of climate change impacts and their identification; difficulty in assessing and implementing adaptation options. Furthermore, regulation and economic incentives may encourage behavioral change, but evidence for the permanence of behaviors resulting from such measures is not clear cut (Berkhout *et al.* 2006). A related example show that the Water Services Regulation Authority (OFWAT, in England and Wales) requires water companies to consider adaptation in their long term plans, yet there is little evidence this has translated into specific adaptations due to conflicting temporal and other economic considerations (Arnell and Delaney 2006). The resources relating to knowledge's, technological and economical restrictions may limit a successful adaptation. These include the various spatial and temporal uncertainties associated with forecast modeling, and low levels of awareness and information amongst policy-makers on the impacts of climate change, as well as a lack of financial resources and assistance to facilitate adaptation interventions. For example, while much of Europe and North America enjoys access to a wealth of observational data and climate modelled projections to inform adaptation policy, many Himalayan and sub-Saharan countries are left with scant historic meteorological information and dependent on coarser, large-scale model predictions (ICIMOD, 2009).

16.5.1.2. Mutable Limits

Mutable limits on adaptation can be defined as "the characteristics to be changeable". Behaviors at the individual and social levels are contingent upon a wide variety of factors. The perceptions of risk, knowledge, experience, and habitual behavior, norms and values determine what is perceived to be a limit to adaptation - at both individual and social levels in any particular society - and what is not. These limits are therefore not absolute and insurmountable but rather socially constructed, subjective and mutable.

A study of elderly people's perceptions of heat wave risks suggests that this relatively vulnerable group does not perceive its vulnerability and therefore does little to adapt (Wolf *et al*., 2009). Research in Norway, for example, shows that in situations where no risk is perceived, little if any action to adapt is undertaken a situation described as complacency (O'Brien *et al*., 2006). Choices are shaped by whether local impacts are known and are anticipated, and by the cognitive–behavioral gap that exists in individuals between knowledge of impacts, values, beliefs, norms and action (Jackson 2005). Both hazards and adaptation research point to the importance of immediate priorities molded, for example, by non-climatic impacts (O'Brien and Leichenko, 2000; O'Brien *et al*., 2004) as drivers of behavioral change.

Yet in the context of limits to adaptation, neither the hazards nor the risk literatures can provide an adequate indication of how mutable and constructed limits may be overcome, given the complex interactions between social and individual characteristics, with a view to securing sustainable societal adaptation in the long term (Adger *et al*., 2009). The survey of observed adaptation in the UK by Tompkins *et al*. (2005), for example, demonstrated that much planning involves building the capacity to deal with future events rather than anticipating and acting on expected specific risks.

16.5.2 Rationale for Limiting Adaptation Activities

While adaptation to climate has a long history, action to adapt to climate change has accelerated more recently and evaluation of efforts is still sparse (e.g. Bassett and Shandas, 2010) reviews a selection of urban climate action plans, 25% of which include adaptation.) A review of over 400 documents addressing adaptation in the Arctic found that few studies went lists to address development and implementation of adaptations, stakeholder acceptability, or performace and durability under diverse scenarios (Pearce *et al*., 2011). While direct evidence is sparse, research on adaptation to climate variability, on anticipated impacts from climate changes, and on policy scenarios provide relevant evidence which identifies several rationale for considering limiting some types of adaptation efforts. As a minimum, adaptation activities might be limited due to the potential for promoting one of several forms of maladaptation. Adaptations can be maladaptive when they do not support increased ability to cope with change, when they worsen a problem, or when they reduce the ability to respond to unexpected events and consequences (Fazey *et al*., 2010). Evaluation of adaptation options recognize the potential that some responses to climate-induced changes will generate negative social and environmental externalities and call for a focus on "sustainable adaptation" options that include consideration of present and future impacts across places and groups and give particular consideration to environmental and social justice and defining an action sustainable if it contributes to or at the very least does not erode these two qualities (Eriksen and Lind, 2009).

16.5.2.1. Avoid Increasing Greenhouse Gas Production and Emissions

Some adaptive strategies may involve significant demand for energy and rely on fossil fuel combustion. The tradeoffs between adaptation and mitigation strategies are receiving more attention, although research is still predominantly/mainly conceptual rather than empirical. Efforts that have been identified as involving substantial tradeoffs include long distance transportation of water which involves large amounts of energy to support pumping and expanding fossil fuel power plants to generate electricity and support air conditioning rather than investing in building rehabilitation and energy conservation retrofits. Although (Hamin and Gurran, 2009) observe that within urban areas the implementation of some adaptation and mitigation policies may involve tradeoffs. (Need to know what adaptation and mitigation chapter says about changes in agricultural practices.) (TO BE ADDED: pickering on skiing, water, and energy.)

16.5.2.2. Avoiding Economic and Policy Failures

The need to simultaneously consider multiple timescales in adaptation planning is often contrasted to the preference for short-term decision-making. Investigations of the processes creating path dependence or "lock-in" identify the potential for institutional and technical structures to reduce the range of possible innovations and observe that some adaptation options may result in higher future adaptation costs, inefficiencies in adaptation (Berkhout, 2002; Chhetri *et al*. 2010; Hallegatte *et al*., 2007). Strategies to increase flexibility through increasing social capital, conditional permitting, market-based mechanisms, allowing for reversibility, and other approaches are generally viewed as positive responses to uncertainty, although some point out that this approach needs careful consideration with respect to when and where it is pursued and potential consequences (Binder *et al*., 2010; Hallegatte, 2009).

Strategies to adapt to one type of threat may increase risks associated with a different threat. In considering options for adaptation to glacial retreat in Nepal, it may not be possible to identify strategies which optimize the reduction of threats from outburst floods, respond to diminished water availability, and maintain the viability of all hydropower systems (Orlove, 2009). The acceptability of risks associated with the different trade-off strategies will require more consideration particularly in linked systems with multiple processes and uses.

Managing shared and limited resources under changing patterns of availability and distribution may make limitations to some forms of adaptation by some parties necessary or preferable. Within coastal management, it is widely observed that structural efforts to protect a portion of shoreline from erosion may increase the pressure on adjacent properties. Other scenarios anticipate adaptation to climate change increasing the demand on a limited resource.

In some instances, it may be useful to limit some types of adaptation in order to assure synchrony between resource use and regulatory frameworks. For example, with changing patterns of fishery stocks, it is possible that adapting which changes pressure on stocks could result in some damage during a period of less regulation or updated management agreement (Hannesson, 2007). (also look at economic game theory (Ekerhovd, 2010)) Uncontrolled increases use of individual wells may threaten groundwater resources in some areas (Sowers *et al*., 2011) (References to be added.).

Some adaptations intentionally or unintentionally work to redistribute risks and burdens across places, groups, and generations. These distributions may conflict with other social goals such as social justice, equity, and proportionality. Insurance is often identified as a strategy for providing a safety net and spreading risk. Government-subsidized insurance against risks associated with weather and climate change-related hazards, such as riverine and coastal flooding, crop loss, and property damage may create incentives for individual decisions that actually increase the risks to individuals, communities, property, and economic assets. Subsidized flood and crop insurance to address current climate-related risks demonstrates that such policies can lead to "morale hazards" or careless regard for a hazard with the expectation that a third-party will provide compensation (Mc Leman and Smit, 2006). The insurance pool for coastal areas may include inland populations and thus spread risks over larger geographic areas and to groups which do not receive benefits of coastal locations. The use of strategic assessment and spatial planning in flood risk management as suggested to improve consistency between strategies and policies by revealing interactions and potential conflicts (Carter *et al*., 2009). Further discussion of insurance mechanisms occurs in chapter 17.XX. Current adaptation choices may potentially result in negative impacts on a future generation whose values and goals cannot be known. While formal economic discounting methods attempt to represent future generations, some critical issues of culture and choice and environmental conditions are excluded in this type of analysis (Adger *et al*., 2009a). Regulation or restriction of activities in one area may encourage the movement of activities to a less restricted or regulated location. (Examples to be added)

16.5.2.3. Minimizing Social and Political Conflicts

The combination of existing stresses and transboundary demands in many river basins facing further pressure under climate changes has attracted some attention to social and political conflict. Differences in the economic resources, social vulnerability, institutional arrangements, and capacity to adapt to changing water availability and demand create potential for unevenness in the region and raises concern that one countries adaptation may cause a net negative impact on another country's ability to adapt (Goulden *et al*., 2009).

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A Nigerian study describes how migration in the West-African Sahel spurred by vulnerability to drought triggers conflict (Nyong, 2006). There is pronounced vulnerability to drought in West Africa's dry zone, and over the last century droughts have increased in magnitude and intensity while inter-annual and spatial variability has increased. As a consequence, pastoralists from the dry Northern zones are moving south into lands occupied by sedentary farmers. Conflicts result. Livestock and farmland is often destroyed in these conflicts, with adverse consequences for food and human security. Traditional institutions for managing conflicts, including climate-related conflicts, exist but have failed to prevent the escalation of pastoralist-farmer clashes. Formal mechanisms for settling disputes (police, courts) have also been tried but met with limited success. In contrast, NGO-supported efforts to mediate the conflict using consultative approaches and support for fodder production to alleviate the resource shortfall have had more success, at least locally. The study emphasizes the need for resolution strategies and capacity building for exposed communities.

Migration as an adaptation is controversial; in different forms is currently used to cope with drought, reduced crop yield and other stresses but it is not widely viewed by governments as an adaptation strategy and may result in additional risks for those who move (Warner, 2010). The impacts of large-scale migration on land and water resources in receiving regions is not currently represented in integrated assessments modeling (REFERENCE TO BE ADDED). The social stresses population movement also present potential for maladaptive outcomes (see human security chapter).

16.5.3. Interactions among Limits

16.5.3.1. Limits can be Additive/Synergistic and Reinforcing

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The term 'synergistic' describes the simultaneous action of separate processes (extrinsic threats or intrinsic biological traits) that have a greater total effect than the sum of individual effects alone (i.e. positive and multiplicative interactions). Climate change is already beginning to exacerbate other extrinsic threats (Brooke at al., 2008). In an experimental context, habitat fragmentation and overharvesting combined with environmental warming in rotifer zooplankton resulted in populations declining up to 50 times more rapidly when combined than when acting singularly (i.e. a nonadditive effect). An excellent real-world example comes from the highland forests of Costa Rica, where 40% of 50 endemic frog and toad species disappeared following synchronous population crashes during the late 1980s. Recent work has linked these extinctions to an interaction between global warming and disease, whereby a retreat of moisture-laden clouds led to a prolonged drying of the montane forest. In a chain of adverse events, this increased the prevalence of pathogenic chytrid fungus Batrachochytrium dendrobatidis, which invaded from lower altitudes. Yet perversely, a wetting of the lowland Costa Rican forests (more rainy days, although no change in mean rainfall) caused population declines in some species due to an enhanced decomposition rate of leaf litter habitat.

Compounding the problems associated with the rate of recent climate change is that species trying to shift distribution to keep pace must now contend with heavily modified landscapes dominated by agriculture, roads and urban development. Even in cases where global warming might allow species to expand their range, these benefits can be outweighed by other local threats such as habitat modification (Brooke at al., 2006). The extinction research has shifted substantially over the last decade, from studies that focussed primarily on the impact of single drivers to those which have demonstrated a positive interaction (synergies, or reinforcing feedbacks) of more than one threat via a combination of approaches (Mora at al., 2007).

16.5.3.2. Limits are Mediated by Human Interactions and Choice

THE FOLLOWING TEXT HAS BEEN TAKEN VERBATIM FROM KEY REFERENCES AND IS AWAITING CITATION AND SYNTHESIS

Adaptations may involve trade-offs between meeting the demands of different sectors, for example, maintaining power production or maintaining in-stream flows for fish (Payne *et al*. 2004 in Kundzewicz *et al*. 2007). Tanaka *et al*. (2006) find that adaptation of California's water supply system will involve significant transfers among water users as well as changes in the operation of groundwater storage and adoption of new technologies. Water markets, already existing in the USA, Canada, Chile and Australia and developing in several other regions of the world, provide a way of achieving such transfers of water (Kundzewicz *et al*., 2007).

Changes in demand or expectations of water services may be necessary or society may have to accept trade-offs between different uses of water (Kundzewicz *et al*., 2007). Socio-political barriers to adaptation can sometimes be overcome, for example Penning-Rowsell *et al*. (2006) found that extreme climate events such as flooding events can trigger change in policy by creating windows of opportunity. Similarly Arnell and Delaney (2006) found that incentives for building adaptive capacity to deal with climate change in the UK public water supply sector depend on an improved awareness of climate change, which can be triggered by extreme events.

Despite the benefits proposed from cooperation over shared water resources in international river basins the literature cites a number of conditions necessary for and barriers or limitations to cooperation that can be political, institutional or geographical. Drieschova *et al*. (2008), in a review of 50 agreements for international river basins, find that there are trade-offs between flexibility in treaties and the enforceability of the agreements. Nevertheless, there are some documented examples of cooperation that incorporates flexibility in response to water variability for African river basins. For example, Conway (2005) describes a treaty for the Nile Basin that has a mechanism to adapt to water deficits during drought situations. Similarly, Kistin and Ashton (2008) find a variety of flexibility mechanisms in formal agreements in the Orange basin in Southern Africa that provide for adaptive capacity in transboundary water management. However, Kistin and Phillips (2007) conclude that not all cooperation produces positive outcomes and that where circumstances are asymmetrical, inequitable or unsustainable outcomes may result from cooperation.

16.5.3.3. Implications of Interactions

Adaptation can be categorised more specifically into various types and forms: in terms of timing it can be 'anticipatory' or 'reactive', and on the level of preparation and outside intervention, it can be either 'planned' or 'autonomous'(Tol *et al*., 2009). Adaptation within natural and ecological systems is reactive, while adaptation at the individual and societal levels can be both anticipatory and reactive in light of observed and expected climate.

Barriers to adaptation are many. Long-term benefits of climate change adaptation may be hidden when producers are faced with significant short-term costs or financial crises (Bradshaw et al, 2004). National-level adaptation options are difficult to prioritize even in countries with high levels of economic and technical capacity (Füssel, 2009). Information and capacity are not the only factors; "what is known, understood and disseminated as information" and issues of power and control of knowledge are also important (Eakin and Wehbe, 2009).

16.6. Effects of Mitigation on Adaptation

16.6.1. Effects of Mitigation Practice on Adaptation Needs and Opportunities

To be elaborated:

- Policy analysis and empirical assessment
- Trade-offs and synergies between mitigation and adaptation
- Example: investment in bioenergy and its effects on food security

16.6.2. Effects of Mitigation Pathways on Adaptation Potential

To be elaborated:

- Integrated assessment modelling (including recent literature incorporating adaptation more explicitly into the models)
- Link with Ch 17 and Working Group III
- Effect of mitigation on the timing of adaptation opportunities, constraints and limits

16.7. Ethical Dimensions of Adaptation Constraints and Limits

''The Parties should protect the climate system for the benefit of the present and future generations of humankind, on the basis of equity and in accordance with their common but different responsibilities in respect to capacities'' (from UNFCCC Article 3). (http://www.unfccc.int/files/essential_background/background_publications_html).

16.7.1. Constraints and Limits Contribute to Inequity

It is now well established that nations, peoples and ecosystems are differentially vulnerable to current and future projected climate change impacts, which themselves are also almost certain to be unequally distributed across the world (Füssel, 2010; Füssel, 2009; IPCC, 2007B). Equity considerations would require the pursuit of equitable solutions that prioritize the most vulnerable, especially given that exposure to impacts for many societies is involuntary (Dellink *et al*., 2009; Fussel, 2010; Paavola and Adger, 2006; Patz *et al*., 2007). Furthermore, risk management responses that shift risk in response to perceived potential limits to adaptation have the potential to exacerbate existing inequalities (Friis, 2010). Even if climate impacts were evenly distributed, differential capacity to adapt or to avoid maladaptation would lead to an unequal distribution of adverse outcomes (Füssel, 2010). It follows that both adaptation capacity in relation to real and perceived limits, and implementation constraints, have a clear potential to create or exacerbate inequitable consequences and outcomes due to climate change.

16.7.1.1. Distributional Justice

Inequity resulting from constraints and limits emerge in several dimensions; namely inter-country equity, inter-generational equity, inter-species equity (Schneider and Lane, 2005), and intra-country or sub-national equity (Thomas and Twyman, 2005). Both constraints and limits are relevant to all of these dimensions.

Inter-species equity is a complex topic and still the subject of evolving ethics unrelated to climate change considerations – value to human society increasingly serves as the most common metric for determining interventions affecting species (Balmford *et al*., 2002). Clearly, differential ecosystem vulnerability is an important determinant of most species' vulnerability to climate change, with some species and ecosystems already severely threatened (IPCC, 2007B). Support for climate change adaptation interventions for species increasingly invokes human and societal benefits as a primary motivation (CBD, 2009).

Inter-generational equity considerations are dominated by discussions of discount rate (Beckerman and Hepburn, 2007; Nordhaus, 2001; Stern *et al*., 2006). This debate largely ignores the challenge of irreversible damages associated with limits to adaptation, especially those that may result from non-linear damage functions (Hanemann, 2008).

Intra-country or subnational equity issues have emerged due to the impacts of recent climate extreme events, clearly this is a wide disparity in vulnerability at subnational level in almost all countries, with extreme climatic conditions highlighting previously concealed limits.

16.7.1.2. Procedural Justice

The relative vulnerability and adaptive capacity of countries is increasingly well known, and is being addressed to some degree by UNFCCC decisions, such as financial support for developing National Adaptation Plans of Action (NAPAs) for the least developed countries (LDCs). These have failed to address urgent adaptation constraints and needs because of poor implementation (Davis and Tan, 2010). The complexity of international law comprises a significant barrier to making the case for addressing the breaching of adaptation limits (Koivurova, 2007). At national and sub-national levels, cultural attitudes can contribute to stakeholder marginalization from adaptation processes, thus preventing some constraints and limits from being identified (such as gender issues and patriarchal conventions).

16.7.2. Adaptation Options Can Have Positive and Negative Externalities

There is a wide variety of positive and negative externalities associated with adaptation to climate change, and some of these have relevance in the context of constraints, limits and opportunities. Positive externalities can be projected at all levels of scale from international to local. Positive externalities may be most closely associated with investments in public goods. Investments in health, food security and disaster risk reduction adaptive strategies are likely to benefit neighbours and the global donor community most through reducing risks of social instability and resource demands. Negative externalities relate most obviously to adaptive strategies that reduce resource availability to neighbours, such as through water security strategies that may reduce availability to downstream neighbours (Eckstein, 2009).

16.7.2.1. Distributional Justice

Positive distributional spill-overs of adaptation that aim to avoid limits are many and would benefit society through their monetisation. An example is the enhancement of ecosystem functions for local adaptation benefits (e.g. restoration of wetlands to avoid the permanent loss of ecosystem services such as food and water security). The downstream externalized benefits would include a reduction in flood risk. Emerging concepts in the form of payments for ecosystem services would internalize these and provide further motivation for more integrated and equitable sharing of the burden and benefits of adaptation, but their implementation faces constraints relating to valuation and verification.

16.7.2.2. Procedural Justice

As real or perceived national or local limits to adaptation are approached, strategies may be encouraged which deprive neighbours of resources. Examples are in the area of trade, where food exports might be reduced or even stopped, with ripple effects across the world economy and a global increase in food prices. Adaptation to water resource limitations may be particularly pernicious (Eckstein, 2009), with local strategies involving water table reductions that affect entire regions, and national strategies that impound water that would have previously flowed between or across political boundaries. There are few agreed international procedural arrangements for addressing or resolving these externalities, compounded by complex international law (Koivurova, 2007).

16.8. Seizing Opportunities, Overcoming Constraints and Limits

To be elaborated:
- Summary, lessons learnt
- Identification of policy needs and opportunities
- Building adaptive capacity
- Promoting social learning
- Strategic vision, need for integration etc
- Identification of research needs and opportunities

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Table 16-1: Cross-sectoral synthesis.

	Framing	Resources (technology, finance, natural, knowledge & information, human)	Institutional	Social and cultural	Rate of change	Metrics	Synthesis
Freshwater resources							
Terrestrial and inland water systems							
Coastal systems and low-lying areas							
Ocean systems							
Food productions systems and food security							
Urban areas							
Rural areas							
Key economic sectors and services							
Human health							
Human security							
Livelihoods and poverty							
Synthesis							

Table 16-2: Cross-regional synthesis.

	Framing	Resources (technology, finance, natural, knowledge & information, human)	Institutional	Social and cultural	Rate of change	Metrics	Synthesis
Africa							
Europe							
Asia							
Australasia							
North America							
Central and South America							
Polar regions							
Small islands							
Open oceans							
Synthesis							

Table 16-3: Strengths and limitations of three popular framings of climate change adaptation assessment (based on information in Fünfgeld and McEvoy, 2011).

Framing	Assessment methodology	Main strengths	Main limitations
Hazards	Standard / integrated impact assessment	• Can produce quantitative estimates of future impacts • Tends to satisfy requirements of robust decision-making • Follows standard impact assessment methodologies widely used in public policy and the private sector	• Statistical downscaling of GCM data is time-consuming • Limited confidence of data used can create an 'uncertainty impasse' • Largely expert-driven, top-down process • Standard impact assessments ignore socio-ecological interactions
Risk	Risk assessment	• Suitable for organisations of various sizes • Fits well with existing organisational systems and processes • Enables linking expected climate change impacts with operational processes	• Effectiveness and ownership of adaptation measures derived from risk assessment is dependent on level of stakeholder engagement • Risk assessment often limited to corporate / organisational risk • Tends to be dominated by concerns about financial and/or economic risks
Vulnerability	Vulnerability assessment	• Bottom-up perspective on climate change adaptation priorities, grounded in local knowledge • Acknowledges and takes account of the distribution of climate change impacts across space and social groups • Assists in designing adaptation actions that respond to local needs • Focus on current vulnerability can help overcome the impasse of uncertainty about future impacts	• Resource-intensive, time-consuming process due to reliance on local data from various sources • Produces mainly qualitative data • Difficult to compare results from different vulnerability assessments across space and time • Visualisation of assessment outputs can be difficult

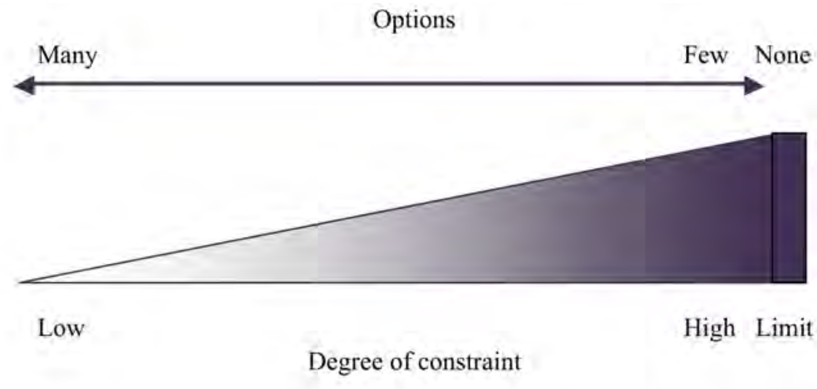

Figure 16-1: An actor's view of adaptation constraints and limits at a given point in time.

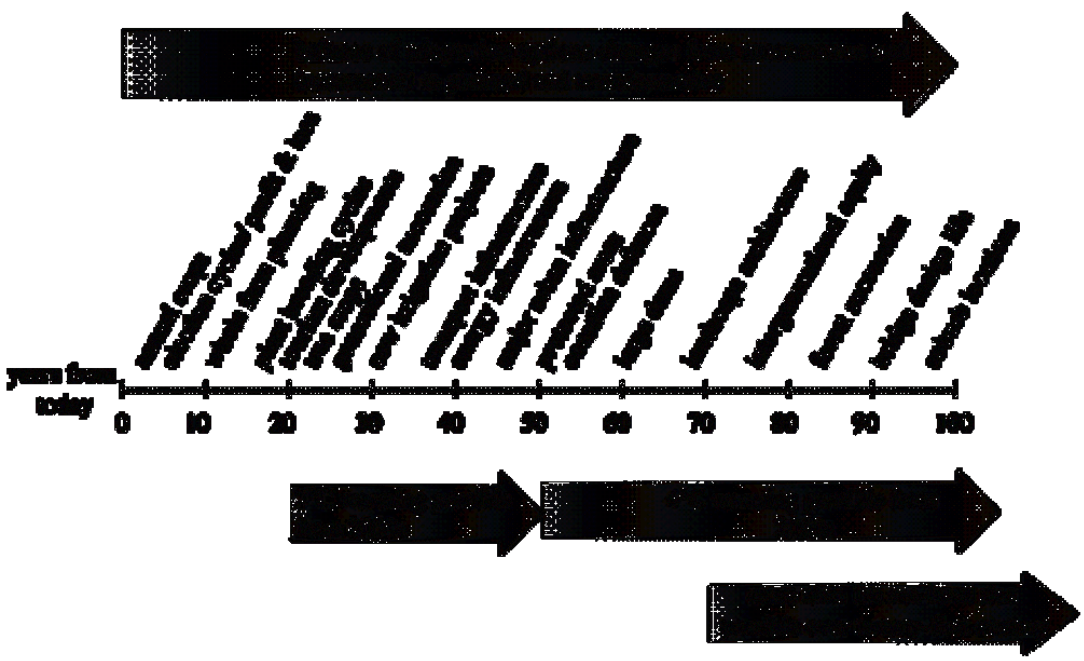

Figure 16-2: Timeline illustrating the lifetimes (sum of lead time and consequence time) of different types of decisions, compared with the time horizons for some global environmental changes, and the changing implications for adaptation (Stafford-Smith *et al.*, 2011:p 199).

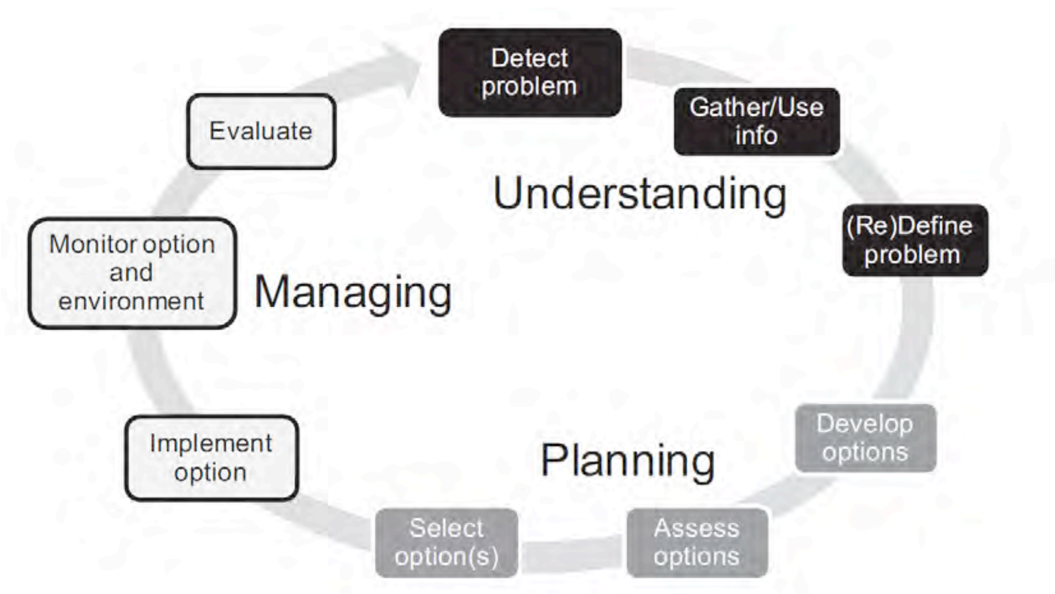

Figure 16-3: Phases and activities associated with the adaptation process (Moser and Ekstrom, 2010).

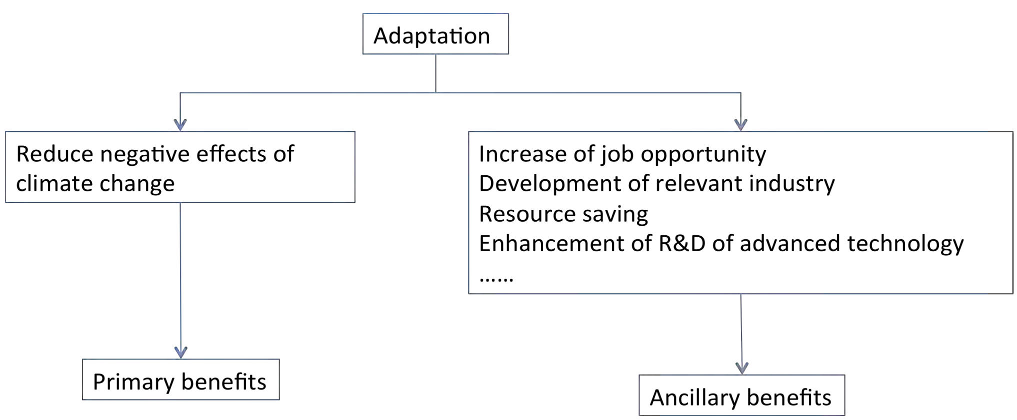

Figure 16-4: Primary and ancillary benefits of adaptation.