IPCC WGII Fourth Assessment Report – Draft for Government and Expert Review

Chapter 18 - Inter-relationships Between Adaptation and Mitigation

Coordinating Lead Authors
R.J.T. Klein (Netherlands), S. Huq (Bangladesh)

Lead Authors
F. Denton (Senegal), T.E. Downing (UK), R.G. Richels (USA), J.B. Robinson (Canada), F.L. Toth (IAEA / Hungary)

Contributing Authors
B. Biagini (GEF / Italy), S. Burch (Canada), J. Wolf (Germany), K. Studd (UK)

Review Editors
M. Grubb (UK), U. Safriel (Israel), A. Allali (Morocco)

Contents

Executive Summary

Both adaptation and mitigation help to reduce the risks of climate change to nature and society [very high confidence]. However, their effects vary over time and place. Mitigation will have global benefits but, owing to the lag times in the climate system, these will hardly be noticeable until 2040 [WG-I]. The benefits of adaptation are largely local to regional in scale but they can be immediate, especially if they also address vulnerabilities to current climate conditions [18.1.1, 18.5.2]. Given these differences between adaptation and mitigation, climate policy is not about making a choice between adapting to and mitigating climate change. If key vulnerabilities to climate change are to be addressed, adaptation is necessary because even the most stringent mitigation efforts cannot avoid further climate change in the next few decades. Mitigation is necessary because reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is possible only at very high social, environmental and economic costs [18.4, 18.6].

Effective climate policy involves a portfolio of adaptation and mitigation actions [very high confidence]. These actions include technological, institutional and behavioural options, the introduction of economic and policy instruments to encourage the use of these options, and research and development to reduce uncertainty and to enhance the options' effectiveness and efficiency [18.4.1, 18.4.2]. Many different actors would be involved in the implementation of these actions, operating on different spatial and institutional scales. Mitigation primarily involves the energy, transportation, forestry and agriculture sectors, whereas actors involved in adaptation represent a large variety of sectoral interests, including agriculture, tourism and recreation, human health, water supply, coastal management, urban planning and nature conservation [18.5, 18.6].

Decisions on adaptation and mitigation are taken at a range of different levels [very high confidence]. These levels include individual households and farmers, private firms and national planning agencies. Effective mitigation requires the participation of the bulk of major greenhouse gas emitters globally, whereas most adaptation takes place at local and national levels. The benefits of mitigation are global, whilst its costs and ancillary benefits arise locally. Both the costs and benefits of adaptation accrue locally [18.1.1, 18.4.2]. Consequently, mitigation is primarily driven by international agreements and ensuing national public policies, whereas most adaptation is driven by private actions of affected entities and public arrangements of impacted communities [18.1.1, 18.6.1].

Inter-relationships between adaptation and mitigation exist at each level of decision-making [high confidence]. Adaptation actions can have (often unintended) positive or negative mitigation effects, whilst mitigation actions can have (also often unintended) positive or negative adaptation effects [18.4.2, 18.5.2]. An example of an adaptation action with a negative mitigation effect is the use of air-conditioning (if the required energy is provided by fossil fuels). An example of a mitigation action with a positive adaptation effect could be the afforestation of degraded hill slopes, which would not only sequester carbon but also control soil erosion. Other examples of such synergies between adaptation and mitigation include rural electrification based on renewable energy sources, planting trees in cities to reduce the heat-island effect and the development of agroforestry systems [18.5.2].

Analysis of the inter-relationships between adaptation and mitigation may reveal ways to promote the effective implementation of adaptation and mitigation actions [medium confidence]. Creating synergies between adaptation and mitigation can increase the cost-effectiveness of actions and make them more attractive to potential funders and other decision-makers. However, synergies provide no guarantee that resources are used in the most efficient manner when seeking to reduce the risks of climate change. Moreover, essential actions without synergetic effects may be overlooked if the creation of synergies becomes a dominant decision criterion [18.6.1]. Opportunities for synergies exist in some sectors (*e.g.*, agriculture, forestry, buildings and urban infrastructure) but they are rather limited in many other climate-relevant sectors [18.5.2]. A lack of both conceptual and empirical information that explicitly considers both adaptation and mitigation makes it difficult to assess the need for and potential of synergies in climate policy [18.7].

Decisions on tradeoffs between the immediate localised benefits of adaptation and the longer-term global benefits of mitigation would require information on the actions' costs and benefits over time [high confidence]. For example, a relevant question would be whether or not investment in adaptation would buy time for mitigation. Global integrated assessment models provide approximate estimates of relative costs and benefits at highly aggregated levels. Intricacies of the inter-relationships between adaptation and mitigation become apparent at the more detailed analytical and implementation levels [18.4.2]. These intricacies, including the fact that adaptation and mitigation operate on different spatial, temporal and institutional scales and involve different actors who have different interests and different beliefs and value systems, present a challenge to the practical implementation of tradeoffs beyond the local scale. In particular the notion of an "optimal mix" of adaptation and mitigation is problematic, since it assumes that there is a zero-sum budget for adaptation and mitigation and that it would be possible to capture the individual interests of all who will be affected by climate change, now and in the future, into a global aggregate measure of well-being [18.4.2, 18.6.1].

People's capacities to adapt and mitigate are driven by similar sets of factors [high confidence]. These factors represent a generalised response capacity that can be mobilised in the service of either adaptation or mitigation. Response capacity in turn is dependent on the societal development pathway. Enhancing society's response capacity through the pursuit of sustainable development pathways is therefore one way of promoting both adaptation and mitigation [18.3]. This would facilitate the effective implementation of both options, as well as their mainstreaming into sectoral planning and development. If climate policy and sustainable development are to be pursued in an integrated way, then it will be important not simply to evaluate specific policy options that might accomplish both goals but also to explore the determinants of response capacity that underlie those options as they relate to underlying socio-economic and technological development paths [18.3, 18.6.3].

18.1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) identifies two options to address climate change: mitigation of climate change by reducing greenhouse gas emissions and enhancing sinks, and adaptation to the impacts of climate change. Most industrialised countries have committed themselves, as signatories to the UNFCCC and the Kyoto Protocol, to adopting national policies and taking corresponding measures on the mitigation of climate change and to reducing their overall greenhouse gas emissions by an average of 5.2% compared to 1990 levels by the period 2008–2012. An assessment of current efforts aimed at mitigating climate change is presented by Working Group III. It shows that these commitments alone would not lead to a stabilisation of atmospheric greenhouse gas concentrations. In fact, no mitigation effort, no matter how rigorous and relentless, is going to prevent climate change from happening in the next few decades, due to the lag times in the global climate system (see relevant chapters in Working Group I). Chapter 1 in this report shows that the first impacts of climate change are already being observed.

Adaptation is therefore a necessity (Parry *et al.*, 1998). Chapter 17 presents examples of adaptations to climate change that are currently being observed but concludes that there are limits and barriers to effective adaptation. Even if these limits and barriers were to be removed, however, reliance on adaptation alone is likely to lead to a magnitude of climate change in the long run to which effective adaptation is only possible at very high social, economic and environmental costs (as, for example, shown for extreme sea-level rise in Europe by Lonsdale *et al.*, 2005; Poumadère *et al.*, 2005; Olsthoorn *et al.*, 2005). It is therefore no longer a question of whether to mitigate climate change or to adapt to it. Both adaptation and mitigation are now essential in reducing the expected impacts of climate change to humans and their environment.

18.1.1 Background and rationale

The level of climate change impacts, and whether or not this level is dangerous (*cf.* Article 2 of the UNFCCC), is determined by both adaptation and mitigation efforts. Adaptation can be seen as direct damage prevention, whilst mitigation would be indirect damage prevention (Verheyen, 2005). In spite of this link, discussions on adaptation and mitigation have been rather unconnected in both climate research and climate policy, involving largely different communities of scholars and negotiators. Only recently have policymakers expressed an interest in exploring inter-relationships between adaptation and mitigation beyond integrated assessment modelling, which has in turn triggered an increased research effort. In particular, the link between the two responses vis-à-vis development is becoming a focus for policy and research.

Traditionally the focus of international climate policy has been on energy policy, with less attention being given to enhancing sinks or to adaptation. As energy supply relies predominantly on fossil fuels (the main source of anthropogenic greenhouse gas emissions), energy policy has been the logical entry point for mitigation. This policy focus was reflected in the IPCC Second Assessment Report (SAR). Since the publication of the SAR, the international climate policy community has become aware that energy policy alone will not suffice in the quest to control climate change and limit its impacts. Climate policy is being expanded from energy policy to consider a wide range of options aimed at sequestering carbon in vegetation, oceans and geological formations, at reducing the emissions of non-CO_2 greenhouse gas emissions, and at reducing the vulnerability of sectors and communities to the impacts of climate change by means of adaptation. Consequently, the IPCC Third Assessment Report (TAR) provided a more balanced treatment of mitigation and adaptation, illustrating the increased interest in adaptation.

Recognising the dual need for adaptation and mitigation, as well as the finitude of funds and the consequent need to explore trade-offs between the two responses, policymakers are faced with an array of questions (GAIM Task Force, 2002). How much adaptation and mitigation would be optimal, when and in which combination? Who would decide, and based on what criteria? Are adaptation and mitigation substitutes or are they complementary to one another? What is the potential for creating synergies between the two responses? How do their costs and effectiveness vary over time? How do the two responses affect, and how are they affected by, development pathways? These are some of the questions that have led the IPCC to include this chapter on inter-relationships between adaptation and mitigation in its Fourth Assessment Report.

The amount of literature that deals explicitly with inter-relationships between adaptation and mitigation is still small compared to that available to other chapters in this report, although it is growing fast. Yet it is also very diverse: there is no consensus in the literature as to whether or not exploring and exploiting inter-relationships between adaptation and mitigation is possible, much less desirable (*cf.* Venema and Cisse, 2004; Klein *et al.*, 2005). The relatively small size of the literature and the lack of consensus pose a challenge to policymakers and academics alike. As a possible first step in addressing this challenge, this chapter not only assesses the available literature on inter-relationships between adaptation and mitigation; it also presents an analytical framework with which such assessment can be done consistently and in line with earlier climate policy analysis.

18.1.2 Structure of the chapter

Box 18.1 summarises the differences, similarities and complementarities between adaptation and mitigation. This chapter then uses this information as the starting point for assessing to what extent adaptation and mitigation are related, and if and how any such inter-relationships could be exploited in climate policy. The chapter is structured as follows. Section 18.2 summarises the knowledge relevant to this chapter that was presented in the IPCC Second and Third Assessment Reports (SAR and TAR). Section 18.3 presents adaptation and mitigation within the context of development pathways, thus providing the background against which policymakers and practitioners operate when acting on climate change. Section 18.4 then frames the challenge of deciding when, how much and how to adapt and mitigate as a decision-theoretical problem, based on which it assesses the existing literature on trade-offs and synergies between adaptation and mitigation (including the potential costs of and damage avoided by adaptation and mitigation). In presenting examples of inter-relationships, Section 18.5 first reviews the respective roles of the stakeholders involved, including the spatial and temporal scales on which they act, and then provides case studies of complementarities and differences as they appear from the literature. Section 18.6 assesses the literature for elements for effective implementation of climate policy that relies on inter-relationships between adaptation and mitigation. Finally, Section 18.7 outlines information needs of climate policy and priorities for research.

Box 18.1: Differences, similarities and complementarities between adaptation and mitigation

IPCC TAR used the following definitions: mitigation is any "anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC, 2001a: 379), whereas "[Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2001a: 365). It follows that mitigation reduces all impacts (positive and negative) of climate change and thus reduces the adaptation challenge whereby adaptation is selective: can take advantage of positive and reduce negative impacts (Goklany, 2005). The effectiveness of diverse mitigation actions can be measured in carbon equivalents while no such common unit is available for measuring the effectiveness of the multitude of adaptation efforts.

Although many determinants of mitigative and adaptive capacity are common, there are a number of important differences between mitigation and adaptation. Given the global nature of climate change, effective mitigation actions need to involve several countries (a sufficient number of major greenhouse gas emitters to foreclose leakage), whereas adaptation activities largely take place at local, regional or national levels. Adaptation rarely expands beyond national boundaries, although some adaptation strategies might result in spillovers over national boundaries (*e.g.*, by changing international commodity prices in agricultural or forest product markets). The costs of mitigation arise locally (economic spillovers are possible) while its benefits are dispersed globally (ancillary benefits might be realised at the local/regional level). Both the costs and benefits of adaptation accrue predominantly locally (with the possibility of spillovers to other regions and to other actors, for example in flood protection or coastal zones). The climate-related benefits of mitigation spread over decades to centuries (near-term ancillary benefits like reduced air pollution are possible) while the benefits of most adaptation efforts (i.e., averted damage) can be realised within years and over decades. Correspondingly, there is a long delay between paying for the mitigation costs and realising their benefits from smaller climate change while the time span between outlays and returns of adaptation is much shorter. This divergence is augmented in analyses adopting positive discount rates. These asymmetries imply that mitigation is driven by international agreements and ensuing national public policies (sometimes supplemented by community-based initiatives), whereas the bulk of adaptation actions are driven by the self-interest of affected private actors and communities, possibly assisted by public policies. Mitigation policies require rigorous implementation measures while adaptation is largely fostered by the self-interest of the affected agents, although rigour might be required in adaptation when it creates a public good like flood protection. Finally, near-term mitigation decisions are necessarily based on uncertain and incomplete information available today (although learning and course correction in the future will be possible), whereas most adaptation actions will gradually emerge over the coming decades and can benefit from improving information about climate change and its impacts.

There are a number of linkages between mitigation and adaptation at different levels of decision-making. Mitigation efforts can foster adaptive capacity if they eliminate market failures and distortions as well as perverse subsidies that prevent actors to make decisions on the basis of the true social costs of the available options. At a highly aggregated scale, mitigation expenditures appear diverting social or private resources and reduce the funds available for adaptation, but in reality the related actors and budgets are different. Both actions change relative prices and so consumption and investment patterns slightly, thus changing the development path of the affected economy, but direct trade-offs are rare special cases. Furthermore, the implications of adaptation activities can be both positive and negative for mitigation endeavours. For example, if afforestation is part of a regional adaptation strategy, it also makes a positive contribution to mitigation. In contrast, if adaptation actions imply increased energy use from carbon emitting sources (*e.g.*, indoor heating and cooling, irrigation and alike), this would affect mitigation efforts negatively.

Mitigation and adaptation are connected in the local, national and international policy portfolios and their relative importance depends on local priorities and preferred approaches in combination with international responsibilities.

18.2 Summary of relevant knowledge in IPCC TAR

Compared to the SAR, two of the Working Groups preparing the IPCC TAR were restructured. The scope assigned to Working Group II was limited to impacts of climate change on sectors and regions and to issues of vulnerability and adaptation, while Working Group III was commissioned to assess the technological, economic, social and political aspects of mitigation. Whereas there were concerted efforts to assess linkages of both mitigation and adaptation to sustainable development (see Chapter 20), there was little room to consider the direct relationships between these two domains. The integration of results and the development of policy-oriented synthesis were therefore difficult (Toth, 2003).

The attempt to establish the foundations of the Synthesis Report (IPCC, 2001a) in the final chapters of Working Groups II and III did not shed light on adaptation-mitigation linkages. Chapter 19 in Working Group II presented "Reasons for concern about projected climate change impacts" in a summary figure that outlines the risks associated with different magnitudes of warming, expressed in terms of the increase in global mean temperature. Largely based on integrated assessment models (IAMs), Chapter 10 in WG III summarised the costs of stabilising CO_2 concentrations at different levels. These two summaries are difficult to compare because the questions as to what radiative forcing and climate sensitivity parameters should be used to bridge the concentration-temperature gap remains unanswered. Moreover, many statements in the two working group reports were themselves distilled from a large number of reviewed studies. Yet the generic assumptions underlying the methods, the specific assumptions of the applications, the selected baseline values for the scenarios, incompatible discount rates, economic growth assumptions and many other postulations implicit in the parameterisation of mitigation and adaptation assessments were largely ignored or remained hidden in the Synthesis Report.

Nonetheless, the TAR presented new concepts for addressing inter-relationships between adaptation and mitigation. Local adaptive and mitigative capacities vary significantly across regions and over time. Superficially they appear to be strongly correlated because they share the same list of determinants. However, aggregate representation across nations or social groups of both mitigation and adaptation is misleading because the capacity to reduce emissions of greenhouse gases and the ability to adapt to it can deviate significantly. As the TAR pointed out: "one country can easily display high adaptive capacity and low mitigative capacity simultaneously (or vice versa)" (IPCC, 2001b: 107; see also Yohe, 2001). In a wealthy nation the damages may fall on a small but influential social group and the costs of adaptation can be distributed across the entire population through the tax system. Yet in the same country, another small group might be hurt by mitigation policies without the possibility to spread this burden. In addition to the conceptual deliberations, the TAR discussed inter-relationships between adaptation and mitigation at two levels: at the aggregated, global and national levels and in the context of economic sectors and specific projects.

The WGII report pointed out that "Adaptation is a necessary strategy at all scales to complement climate change mitigation efforts" (IPCC 2001c: 6) but also elaborates the complex relationships between the two domains at various levels. Some relationships are synergistic while others are characterised by trade-offs. The report noted the arguments in the literature about the trade-off between adaptation and mitigation because resources committed to one are not available for the other but notes that this is "debatable in practice because the people who bear emission reduction costs or benefits often are different from those who pay for and benefit from adaptation measures" (IPCC 2001c: 94). From the dynamic perspective, "climatic changes today still are relatively small, thus there is little need for adaptation, although there is considerable need for mitigation to avoid more severe future damages. By this logic, it is more prudent to invest the bulk of the resources for climate policy in mitigation, rather than adaptation" (IPCC 2001c: 94). Yet, as WGIII noted, one should bear in mind the intergenerational trade-offs. The impacts of today's climate change investments on future generations' opportunities should also be considered. Investments might enhance the capacity of future generations to adapt to climate change, but at the same time may displace investments that could create other opportunities for future generations (IPCC 2001b: 484).

WGIII Chapter 10 outlined the iterative process in which nations balance their own mitigation burden against their own adaptation and damage costs. "The need for, extent and costs of adaptation measures in any region will be determined by the magnitude and nature of the regional climate change driven by shifts in global climate. How global climate change unfolds will be determined by the total amount of greenhouse gas emissions that, in turn, reflects nations' willingness to undertake mitigation measures. Moreover, balancing mitigation and adaptation efforts largely depends on how mitigation costs are related to net damages (primary or gross damage minus damage averted through adaptation plus costs of adaptation). Both mitigation costs and net damages, in turn, depend on some crucial baseline assumptions: "economic development and baseline emissions largely determine emission reduction costs, while development and institutions influence vulnerability and adaptive capacity" (IPCC 2001b: 604).

Discussions of inter-relationships between adaptation and mitigation are sparser at the sector/project level. Some chapters in WGII noted the mitigation linkages when discussing climate change impacts and adaptation in selected sectors, primarily those related to land-use, agriculture and forestry. WGII Chapter 5 noted that "[A]fforestation in agroforestry projects designed to mitigate climate change may provide important initial steps towards adaptation" (IPCC 2001c: 296). Chapter 8 emphasised sustainable forestry, agriculture and wetlands practices that yield benefits in watershed management and flood/mudflow control but involve trade-offs such as wetlands restoration helping to protect against flooding and coastal erosion, but in some cases increasing methane release.

WGII Chapter 12 observed the complexities in land management in Australia and New Zealand "where control of land degradation through farm and plantation forestry is being considered as a major option, partly for its benefits in controlling salinisation and waterlogging, and possibly as a new economic option with the advent of incentives for carbon storage as a greenhouse mitigation measure (IPCC 2001c: 608). Chapter 15 mentioned soil conservation practices (*e.g.*, no tillage, increased forage production, higher cropping frequency) implemented as mitigation strategies in North America (IPCC 2001c: 756). It observed that the Kyoto Protocol mentions human-induced land-use changes and forestry activities (afforestation, reforestation, deforestation) as sinks of greenhouse gases for which sequestration credits can be claimed and that agricultural sinks may be considered in the future. The market emerging in North America to enhance carbon sequestration leads to land management decisions with diverse effects. The negative consequences of reduced tillage implemented to enhance soil carbon sequestration include the increased use of pesticides for disease, insect and weed management; capturing carbon in labile forms that are vulnerable to rapid oxidation if the system is changed; and reduced yields and cropping management options and increased risk for farmers. The beneficial consequences of reduced tillage (especially no-till) are reduced input costs (*e.g.*, fuel) for farmers; increased soil moisture and hence reductions in crop water stress in dry areas; reduction in soil erosion; and improved soil quality (IPCC 2001c: 758).

In chapters dealing with other sectors affected by climate change impacts and mitigation, less attention was paid to their linkages. WGII Chapter 8 mentioned energy end-use efficiency in buildings having both mitigation and adaptation benefits, as improved insulation and equipment efficiency can reduce the vulnerability of structures to extreme temperature episodes and emissions. An example of the remote causalities between mitigation and adaptation across space and time was provided by Chapter 17. Small island states are recognised to be vulnerable to climate change and tourism is a major source of income for many of them. While over the long term, milder winters in their current markets could reduce the appeal of these islands as tourist destinations, they could be even more severely harmed by increased airline fares "if greenhouse gas mitigation measures (*e.g.*, levies and emission charges) were to result in higher costs to airlines servicing routes between the main markets and small island states" (IPCC 2001c: 862).

Finally, WGII Chapter 8 drew attention to a linkage between adaptation and mitigation in the Kyoto Protocol that establishes a surcharge ("set-aside") on mitigation activities implemented as Clean Development Mechanism projects. "One key issue is the size of the "set-aside" from CDM projects that is dedicated to funding adaptation. If this set-aside is too large, it will make otherwise viable mitigation projects uneconomic and serve as a disincentive to undertake projects. This would be counterproductive to the creation of a viable source of funding for adaptation" (IPCC 2001c: 444).

18.3 Response capacity and development pathways

As outlined in the IPCC TAR (Working Group II, Ch.18 and Working Group III, Ch. 1) and discussed at more length in Chapter 17 of this volume and Chapter 12 of the Working Group III report, the ability to implement specific adaptation and mitigation measures is dependent upon the existence and nature of adaptive and mitigative capacity, which makes such measures possible and affects their extent and effectiveness. In that sense, specific adaptation and mitigation measures are rooted in their respective capacities (Adger and Vincent, 2005; Brooks *et al*, 2005; Adger e*t al*, 2003; Yohe, 2001).

Adaptive capacity has been defined in this assessment report (Working Group II, Ch.17.3.1) as "the ability or potential of a system to respond successfully to climate variability and change." In a parallel way, mitigative capacity has been defined in the 4AR as the "ability to diminish the intensity of the natural (and other) stresses to which it might be exposed," (Working Group III, Ch. 1.1.1). Since this definition suggests that a group's capacity to mitigate hinges on the severity of impacts to which it is exposed, Winkler *et al* (2006) have suggested that mitigative capacity be defined instead as "a country's ability to reduce anthropogenic greenhouse gases or enhance natural sinks". Clearly these two categories are closely related, though in accordance with the differences between adaptation and mitigation measures discussed in section 18.1 above, capacities also differ somewhat. In particular, since adaptation measures tend to be both more geographically dispersed and smaller in scale than mitigation measures (Ruth, 2005; Dang *et al.*, 2003), adaptive capacities refer to a slightly broader and more general set of capabilities than mitigative capacities. Despite these minor differences, however, adaptive and mitigative capacities are driven by similar sets of factors.

The term response capacity may be used to describe the ability of humans to manage both the generation of greenhouse gases and the associated consequences (Tompkins and Adger, 2003). As such, response capacity represents a broad pool of resources, many of which are related to a group or nation's level of socio-technical and economic development, which may be translated into either adaptive or mitigative capacity. Socio-cultural dimensions such as belief systems and cultural values, which are often not addressed to the same extent as economic elements (Handmer *et al*., 1999), can also affect response capacity (See Third Assessment Report & Chapter 12 Working Group III).

Although the concept of response capacity is new to the IPCC, and has yet to be sufficiently investigated in the literature, efforts have been made to define the nature and determinants of its conceptual components, adaptive and mitigative capacity. With regard to mitigative capacity, Yohe (2001) has suggested the following list of determinants, which play out at the national level:

- range of viable technological options for reducing emissions;
- range of viable policy instruments with which the country might effect the adoption of these options;

- structure of critical institutions and the derivative allocation of decision-making authority;
- availability and distribution of resources required to underwrite their adoption and the associated, broadly defined opportunity cost of devoting those resources to mitigation;
- stock of human capital, including education and personal security;
- stock of social capital, including the definition of property rights;
- country access to risk-spreading processes (*e.g.*, insurance, options and futures markets, *etc.*);
- ability of decision makers to manage information, the processes by which these decision makers determine which information is credible and the credibility of decision makers themselves.

In the context of developing countries, many of which possess limited institutional capacity and access to resources, mitigative and adaptive capacity could be fashioned by other determinants. For instance, political will and the intent of decision makers (Burton *et al*., 2001), and the ability of societies to form networks through collective action that insulate them against the impacts of climate change (Woolcock and Naryan, 2000) may be especially important in developing countries, especially in societies where policy instruments are not fully developed, and where institutional capacity and access to resources are limited.

Yohe suggests a similar set of determinants for adaptive capacity, but adds the availability of resources and their distribution across the population. Recent research has sought to offer empirical evidence that demonstrates the relative influence of each of these determinants on actual adaptation (Yohe and Tol, 2002). These determinants of both adaptive and mitigative capacity expand on those identified in the Third Assessment Report and agree closely with those offered by Moss *et al.*, (2001) and Adger *et al.*, (2004). The linkages between adaptive and mitigative capacity are demonstrated by the striking similarities between these sets of determinants, which show that both the ability to adapt and the ability to mitigate depend on a mix of social, biophysical and technological constraints (Tompkins and Adger, 2003). Recent research has pointed to the necessity of broadening these lists of determinants to include other important factors such as socio-political aspirations (Haddad, 2005), risk perception and perceived adaptive capacity (Grothmann and Patt, 2005) and political will (Winkler *et al.*, forthcoming).

These discussions of determinants indicate the close connection that exists between response capacities and the underlying socio-economic and technological development paths that give rise to those capacities. In important respects, the determinants listed above are important characteristics of such development paths. Those development paths, in turn, underpin the baseline and stabilisation emission scenarios that will be discussed in Chapter 3 of Working Group III and used to estimate emissions, climate change and associated climate change impacts. As a result, the determinants of response capacity can be expected to vary across the underlying emission scenarios reviewed in this Fourth Assessment Report. The climate change and climate change impact scenarios assessed in the Fourth Assessment Report will be primarily based on the SRES family of emission scenarios, which define a spectrum of different development paths, each with associated socio-economic and technological conditions and driving forces. Each family of emission scenarios will therefore give rise to a different set of response capacities, and thus different likely or even possible levels of adaptation and mitigation.

This situation is summed up in Figure 18.1, which shows adaptation and mitigation measures as being rooted in adaptive and mitigative capacity. The adaptive and mitigative capacities are in turn contained within, and strongly affected by, the nature of the development path in which they exist. The figure also illustrates that adaptation, mitigation and their respective capacities overlap substantially but are not identical.

The concept of development paths is discussed at more length in Chapters 12, 2 and 3 of the Working

Group III report. Here, it is sufficient to think of a development path as a complex array of technological, economic, social, institutional and cultural characteristics that define an integrated trajectory of the interaction between human and natural systems over time at a particular scale. Such technological and socio-economic development pathways find their most common expression in the form of integrated scenarios (Swart *et al.*, 2003, Grubb *et al*, 2002, Geels and Smit, 2000), but are also incorporated into studies of technological diffusion (Rogers, 2003; Berkhout, 2002; Grubler, 2000; Andersen, 1998; Dupuy, 1997; Foray and Grubler, 1996), socio-technical systems (Geels, 2004), and path-dependency and lock-in (Unruh and Carrillo-Hermosilla, 2006; Geels, 2005; Sarkar, 1998; Arthur, 1989). Technological and social pathways co-evolve through a process of learning, coercion, and negotiation, which transform simple configurations of artefacts into seamless socio-technical webs (Rip and Kemp, 1998).

In the climate change context, the TAR noted that "climate change is thus a potentially critical factor in the larger process of society's adaptive response to changing historical conditions through its choice of developmental paths" (Banuri *et al.*, 2001). Later in the same volume, the following typology of critical components of development paths is presented (Toth *et al.*, 2001):

- Technological patterns of natural resource use, production of goods and services and final consumption;
- Structural changes in the production system;
- Spatial distribution patterns of population and economic activities;
- Behavioural patterns that determine the evolution of lifestyles.

The influence of economic trajectories and structures on the adaptability of a nation's development path is important in terms of the patterns of carbon-intensive production and consumption that generate greenhouse gases (Ansuategi and Escapa, 2002; Smil, 2000), the costs of policies that drive efficiency gains through technological change (Azar and Dowlatabadi, 1999), and the occurrence of market failures which lead to unsustainable patterns of energy use and technology adoption (Jaffe *et al*, 2005; Jaffe and Stavins, 1994).

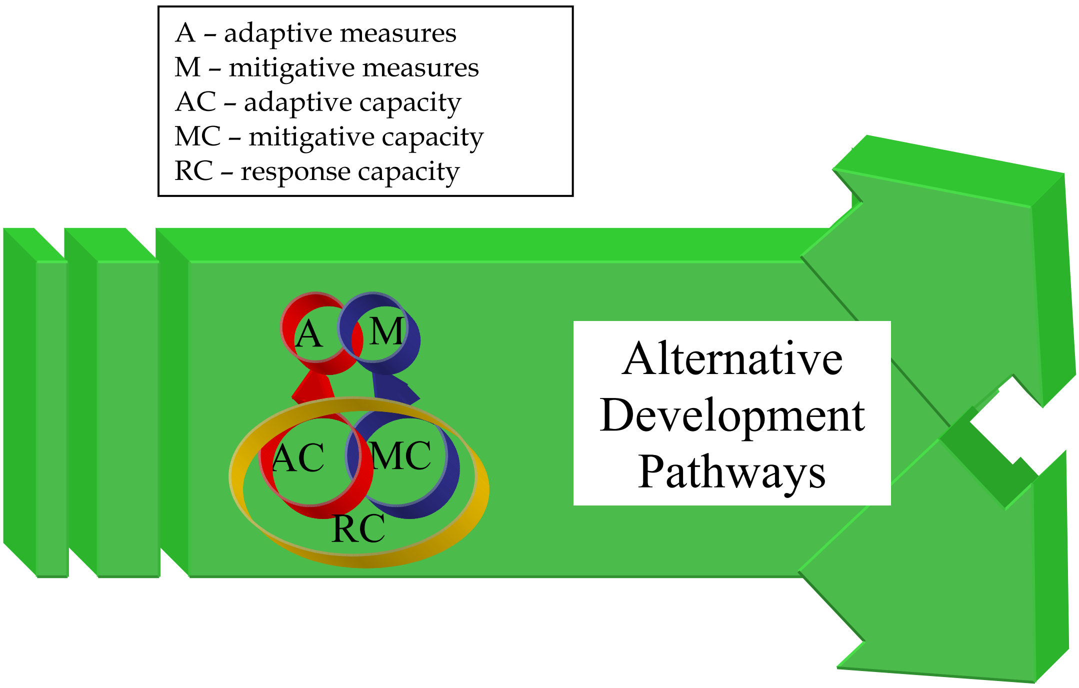

Figure 18.1: *Adaptation and mitigation are made possible through response capacity, which in turn is deeply rooted in the underlying socio-economic and technological development path which gives rise to these capacities. Different development paths imply different response capacities.*

In addition to these components, scholars from widely varying disciplines and backgrounds have noted the importance of institutional structures and trajectories (Adger *et al* 2005; Ruth, 2005; Pierson, 2004; Agrawal, 2001; Olsen and March, 1989) and cultural factors such as values (Baron and Spranca, 1997; Stern and Dietz, 1994), discourses (Adger *et al,* 2001), and social rules (Geels, 2004), as elements of development paths that help determine the ability of a system to respond to change.

The importance of the connection shown in Figure 18.1 among measures, capacities and development paths is threefold. First, as pointed out in the Third Assessment Report, a full analysis of the potential for adaptation or mitigation policies must also include some consideration of the capacities in which these policies are rooted. This is increasingly being reflected in the literature being assessed in both regional/sectoral and conceptual chapters of this assessment. Second, such an analysis of response capacities should, in turn, encompass the nature and potential variability of underlying development paths that strongly affect the nature and extent of those capacities. This suggests the desirability of an integrated analysis of climate policy options that assesses the linkages among policy options, response capacities and their determinants, and underlying development paths. Although such an integrated assessment was proposed in the Synthesis Report of the IPCC's Third Assessment Report (Watson, 2002)*,* this type of assessment is as yet in its infancy.

Third, the linkages between climate policy measures and development paths described here suggest a potential disconnection between the degree of adaptation and/or mitigation that is possible and that which may be desired in a given situation. On the one hand, the development path will determine the response capacity of the scenario. On the other, the development path will strongly influence levels of greenhouse gas emissions, associated climate change, the likely degree of climate change impacts and thus the desired mitigation and/or adaptation in that scenario (Nakicenovic, 2000; Metz *et al.*, 2002; Swart *et al.*, 2003).

However, there is no particular reason that the response capacity and desired levels of mitigation and/or adaptation will change in compatible ways. As a result, particular development paths might give rise to levels of desired mitigation and adaptation that are at odds with the degree of adaptive and mitigative capacity available. For example, particular development path scenarios that give rise to very high emissions might also be associated with a slower growth, or even a decline, in the determinants of response capacity. Such might be the case in scenarios with high degrees of military activity or a collapse of international cooperation. In such cases, climate change impacts could increase, even as response capacity declines.

The linkages among climate policy, response capacities and development paths suggested above help us to understand the nature of the relationship between climate policy and sustainable development. There is a small but growing literature on the nature of this relationship (Cohen *et al.*, 1998; Munasinghe and Swart, 2000; Schneider *et al.*, 2000; Banuri, 2001; Robinson and Herbert, 2001; Smit *et al.*, 2001; Beg *et al.*, 2002; Markandya and Halsneas, 2000; Metz et al., 2002; Najam *et al.*, 2003; Swart *et al*., 2003; Wilbanks, 2003). Much of this literature emphasises the degree to which climate change policies can have effects, sometimes called ancillary benefits or co-benefits, which will contribute to the sustainable development goals of the jurisdiction in question (Van Asselt *et al*, 2005). This amounts to viewing sustainable development through a climate change lens. It leads to a strong focus on integrating sustainable development goals and consequences into the climate policy framework and on assessing the scope for such ancillary benefits. For instance, reductions in greenhouse gas emissions might reduce the incidence of death and illness due to air pollution and benefit ecosystem integrity – both of which are elements of sustainable development (Cifuentes *et al.*, 2001). The challenge then becomes ensuring that actions taken to address environmental problems don't obstruct regional and local development (Beg *et al.*, 2002). A variety of case studies demonstrate that regional and local development can in fact be enhanced by projects that contribute to adaptation and mitigation. Urban food growing in two UK cities, for example, has resulted in reduced crime rates, improved biodiversity and reduced transport-based emissions (Howe and Wheeler, 1999). Similarly, agro-ecological initiatives in Latin America have helped to preserve the natural resource base while empowering rural communities (Altieri, 1999). The concept of networking and clustering used mainly in entrepreneurial development and increasingly seen as a tool for the transfer of skills, knowledge and technology represents an interesting concept for countries that lack the necessary adaptive and mitigative capacities to combat the negative impacts of climate change (Klerk *et al*, 1999).

An alternative approach is based on the finding in the Third Assessment Report that it will be extremely difficult and expensive to achieve stabilisation targets below 650 ppm from baseline scenarios that embody high emission development paths. Conversely, low emission baseline scenarios may go a long way toward achieving low stabilisation levels even before climate policy is included in the scenario (Morita *et al.*, 2001). This recognition leads to an approach to the linkages between climate policy and sustainable development - equivalent to viewing climate change through a sustainable development lens - that emphasises the need to study how best to achieve low emission development paths (Metz *et al.*, 2002; Robinson *et al.*, 2003; Swart *et al.*, 2003).

It has further been argued that sustainable development might decrease the vulnerability of developing countries to climate change impacts (IPCC 2001b), thereby having implications for the necessary amount of both adaptation and mitigation efforts. For instance, economic development and institution building in low-lying, highly populated coastal regions may help to increase preparedness to sea level rise and decrease vulnerability to weather variability (McLean *et al.*, 2001). Similarly, investments in public health training programmes, sanitation systems and disease vector control would both enhance general health and decrease vulnerability to the future effects of climate change (McMichael *et al.*, 2001). Framing the debate as a development problem rather than an environmental one helps to address the special vulnerability of developing nations to climate change while acknowledging that the driving forces for emissions are linked to the underlying development path (Metz *et al.*, 2002). Of course it is important also to acknowledge that climate change policy cannot be considered a substitute for sustainable development policy even though it is determined by similar underlying socio-economic choices (Najam *et al.*, 2003).

Both approaches to linking climate change to sustainable development suggest the desirability of integrating climate policy measures with the goals and attributes of sustainable development (Robinson *et al*, 2006; Van Asselt *et al*, 2005; Adger *et al*, 2003; Robinson and Herbert, 2001). This suggests an additional reason to focus on the inter-relationships between adaptation, mitigation, response capacity and development paths indicated in Figure 18.2. If climate policy and sustainable development are to be pursued in an integrated way, then it will become important not simply to evaluate specific policy options that might accomplish both goals, but also to explore the determinants of response capacity that underlie those options and their connections to underlying socio-economic and technological development paths (Swart *et al.*, 2003). Such an integrated approach also might be the basis for productive partnerships with the private, public, NGO and research sectors (Robinson *et al.*, 2006).

There is general agreement that sustainable development involves a comprehensive and integrated approach to economic, social and environmental processes (Munasinghe, 1992; Banuri *et al.*, 1994; Najam *et al*., 2003). However, early work tended to emphasise the environmental and economic aspects of sustainable development, overlooking the need for analysis of social, political or cultural dimensions (Barnett, 2001; Lehtonen, 2004; Robinson, 2004) . More recently, the importance of social, political and cultural factors – for example, poverty, social equity, and governance – has increasingly been recognised (Lehtonen, 2004) to the point that social development, which also includes both political and cultural concerns, is now given equal status as one of the ‘three pillars’ of sustainable development. This is evidenced by the convening of the World Summit on Social Development in 1995 and the fact that the Millennium Summit in 2000 highlighted poverty as fundamental in bringing balance to the overemphasis on the environmental aspects of sustainability. The environment-poverty nexus is now well recognised and the linkage between sustainable development and achievement of the Millennium Development Goals (MDGs) (United Nations, 2000) has been clearly articulated (Jahan and Umana, 2003). In order to achieve real progress in relation to the MDGs, different countries will settle for different solutions (Dalal-Clayton, 2003), and these development trajectories will have important implications for the mitigation of climate change.

In attempting to follow more sustainable development paths, many developing nations experience unique challenges, such as famine, war, social, health and governance issues (Koonjul, 2004). As a result, past economic gains in some regions have come at the expense of environmental stability (Kulindwa, 2002), highlighting the lack of exploitation of potential synergies between sustainable development and environmental policies. In the water sector, for instance, response capacity can be improved through co-ordinated management of scarce water resources, especially since reduction in water supply in most of the large rivers of the Sahel can affect vital sectors such as energy and agriculture both of which are dependent on water availability for hydroelectric power generation and agricultural production (Ikeme, 2002). Technology, institutions, economics and socio-psychological factors, which are all elements of both response capacity and development paths, affect the ability of nations to build capacity and implement sustainable development, adaptation and mitigation measures (Nederveen *et al.*, 2003).

18.4 Potential costs of and damages avoided by adaptation and mitigation

18.4.1 Framing the decision problem

A portfolio of actions is available for reducing the risks of climate change within which each option requires evaluation of its individual and collective merits. Policymakers need to decide what constitutes the "right" mix of near-term actions in the face of the many long-term uncertainties. The actions can be grouped into two categories: First, investments in *mitigation* are actions that eliminate or reduce greenhouse gas emissions, or remove greenhouse gases from the atmosphere, as well as research to facilitate future mitigation. Second, investments in *adaptation* are actions that help human and natural systems to adjust to climate change should it occur, as well as research to facilitate future adaptation.

At the highest level of abstraction, five interactions between adaptation and mitigation can be identified:

1. Adaptation and mitigation are policy substitutes; the more is done of the one, the less need to be done of the other.
2. Adaptation and mitigation compete for finite resources; the more is done of the one, the less can be done of the other.
3. Adaptation to climate change can and will affect emissions (e.g., air conditioning).
4. Mitigation of emissions will change vulnerability to climate change (e.g., wind power).
5. Both adaptation and mitigation are influenced by, and influence development.

Climate change engages a multitude of decision-makers, both spatially and temporally. The UNFCCC and its subsidiary bodies have largely focused on mitigation, and it is also discussed independently by member Parties. More recently, an increasing interest at the grassroots level has yielded more local mitigation activities. Adaptation decisions embrace both the public and private sector as some decisions involve large construction projects in the hands of public sector decision-makers while other decisions are localised, involving many private sector agents.

It is difficult and perhaps counterproductive to explore the payoffs from various types of investments without a conceptual framework for thinking about their interactions. Decision analysis provides one such framework (Raiffa 1968, Keeney and Raiffa 1976) that allows for the systematic evaluation of near-term options in light of the careful consideration of the potential consequences. The next several decades will require a series of decisions on how best to reduce the risks from climate change. [There will no doubt be opportunities for learning and midcourse corrections.] The immediate challenge facing policy makers is what actions are currently appropriate and are likely to be robust in the face of the many long-term uncertainties.

Figure 18.2 provides a caricature of the climate policy "decision tree". In the language of decision analysis, the squares represent points at which decisions are made, the circles represent the reduction of uncertainty in the outcomes (if any), and the arrows indicate the wide range of possible decisions and outcomes. The first decision node summarises some of today's investment options. How much should we invest in mitigation, how much in adaptation? How much should be invested in research? Once we act, we have an opportunity to learn and make mid-course corrections. The outcome nodes represent some of the types of learning that will occur between now and the next set of decisions. The outcomes are uncertain; the uncertainty may not be resolved but there will be new information which may influence future actions. [Hence, the expression "act, then learn, and then act again" (Manne and Richels, 1992).]

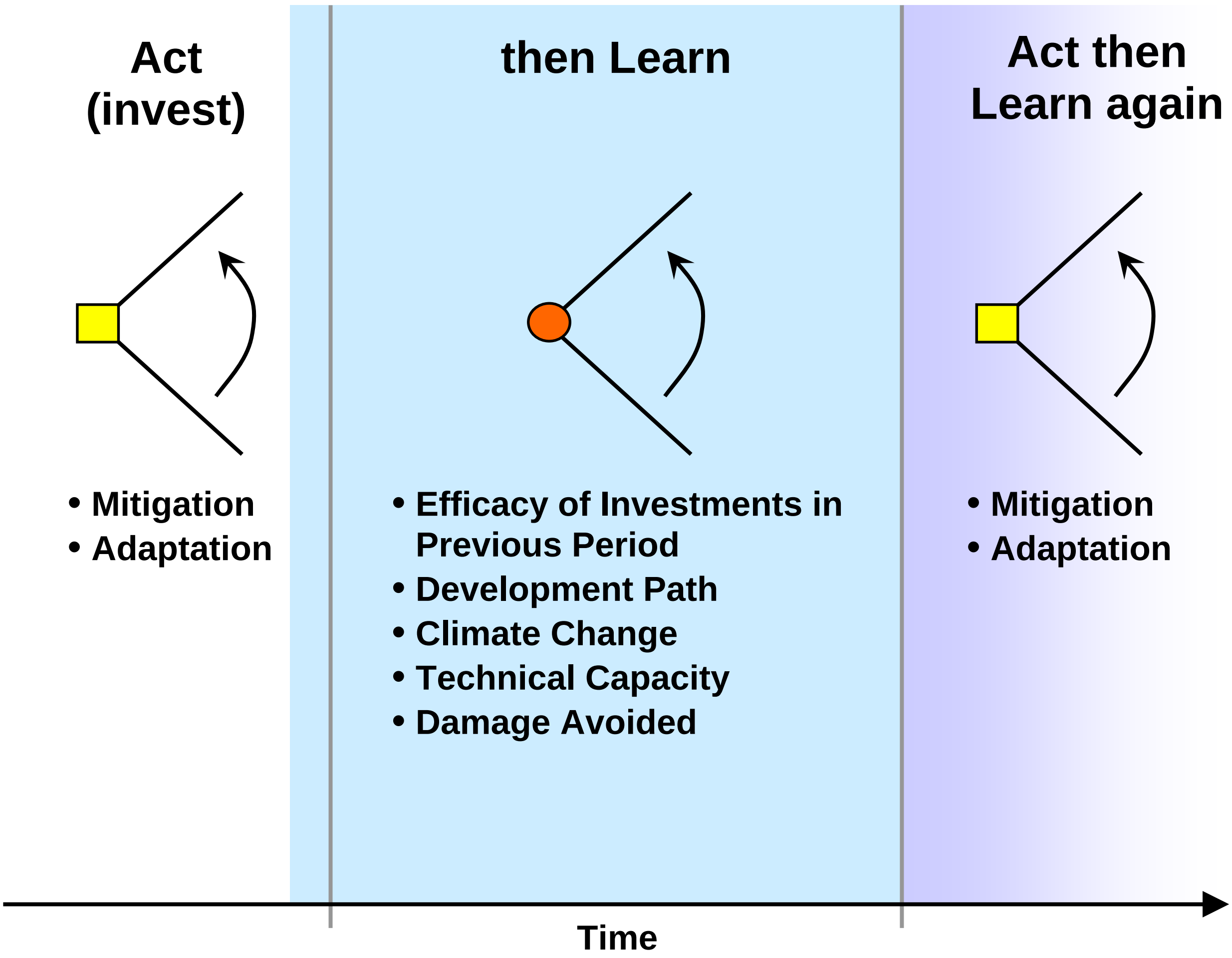

Figure 18.2: *The dynamic nature of the climate policy process. The squares are decision nodes, with arrows indicating the wide range of actions. The circles are outcome nodes, with wide range of potential consequences.*

18.4.2 Studies of trade-offs and synergies in global scale analysis

Initial studies tended to focus on the relationship between mitigation and damages avoided . More recently, the literature has begun to focus on the relationship between adaptation and damages avoided. Ultimately, better knowledge about the interaction between mitigation and adaptation actions in terms of damages avoided would be useful. However, such research is at a very rudimentary stage.

Analysts working on global-scale climate analyses remain apart in their formulation of the adaptation-mitigation linkages. Some consider them as substitutes and seek the optimal policy mix, while others emphasise the diversity of impacts (with little scope for adaptation in some sectors) and the asymmetry of social actors who need to mitigate versus those who need to adapt (Tol, 2005a). Note these positions are not contradictory.

Cost-benefit analyses are phrased as the trade-off between mitigation costs on the hand and adaptation costs and residual damages on the other. As a recent example, Nordhaus (2001) estimates the economic impact of the Kyoto-Bonn Accord with the RICE-2001 model. Without the participation of the USA, the resulting emission path remains below the efficient reduction policy (that balances estimated costs and benefits of emission reductions) whereas the original Kyoto Protocol implied higher than efficient abatement. This is a common finding in the cost-benefit literature, driven primarily by the relatively low estimates of the marginal damage costs (Tol, 2005b). Cost-benefit models are recognised by many as sources of guidance on the magnitude and rate of optimal climate policy, while others criticise them for ignoring the sectoral (economic and social), spatial and temporal distances between those who need to mitigate versus those who need to adapt to climate change.

The Tolerable Windows Approach (TWA) adapts a different approach to integrating mitigation and impact/adaptation concerns. The ICLIPS (Integrated Assessment of Climate Protection Strategies) model identifies fields of long-term greenhouse gas emission paths that prevent rates and magnitudes of climate change leading to "unacceptable" regional or sectoral impacts without imposing "intolerable" mitigation costs on societies. This "relaxed" cost-benefit framework can be used to explore trade-offs between climate change or impact constraints on one hand, and mitigation cost limits in terms of the existence and size of long-term emission fields on the other hand. For any given impact constraint, increasing the acceptable consumption loss due to emission abatement expenditures increases the emission field and allows higher near-term emissions but involves higher mitigation rates and costs in later decades. Conversely, for any given mitigation cost limit, increasing the tolerated level of climate impact also enlarges the emission field and allows higher near-term emissions (Toth *et al.*, 2002; 2003a,b). This formulation allows the exploration of side-payments for enhancing adaptation in order to tolerate impacts from larger climate change. The TWA is helpful in exploring the feasibility and implications of crucial social decisions (acceptable impacts and mitigation costs) but, unlike CBA, it cannot provide an optimal policy.

Cost-effectiveness analyses (CEAs) depict a rather remote relationship between mitigation and adaptation. They implicitly assume that some sort of a global climate change target can be agreed upon that would keep all climate change impacts at the level that can be managed via adaptation or taken as "acceptable losses". Global CEAs have proliferated since the publication of the TAR. In addition to exploring least-cost strategies to stabilise CO_2 concentrations, CEAs are also adopted to stabilising radiative forcing and global mean temperature. While most analyses are deterministic in the sense that they assume that we know the true state of the world, there is also a body of literature that models the "act, then learn, then act again" nature of the decision problem.

The competition of adaptation and mitigation measures for a finite budget has not been studied in much detail. Schelling (1995) questions whether the money that developed countries' governments plan to spend on greenhouse gas emission reduction, ostensibly to the benefit of the children and grandchildren of the people in developing countries, cannot be spent to greater benefit. As a partial answer to that question, Tol (2005c) shows that development aid is a better mechanism to reduce climate change impacts on infectious disease (e.g., malaria) than is emission abatement; the same study also shows that this result does not carry over to other impacts.

Some studies estimate the change in greenhouse gas emissions due to the impacts of climate change (Berrittella *et al.,* forthcoming, for tourism; Bosello *et al*., forthcoming, for health). They find that emissions increase in some places and some sectors, and decrease elsewhere. The disaggregated effects are small compared to the projected growth in emissions, while the net effect is negligible. Similarly, Fankhauser and Tol (2005) show that the impact of climate change on the growth of the economy and greenhouse gas emission is small compared to the uncertainty in the projections. Fisher *et al* (forthcoming) reach a similar conclusion for population projections. As there are so few studies, focusing on a few sectors only, these conclusions are preliminary.

Other studies estimate the change in vulnerability to climate change due to emission abatement; for instance, a shift to wind and water power or biofuels would reduce carbon dioxide emissions, but increase exposure to the weather and climate (e.g., Dang *et al.*, 2003).

Emission reduction is likely to slow economic growth, but this effect is probably small if smart abatement policies are used (Weyant, 2004). However, small economic losses in the OECD may be amplified in poor exporters of primary products (i.e., many African countries). Tol and Dowlatabadi (2001) use this mechanism to demonstrate an interesting trade-off between mitigation and adaptation. Taking malaria as a climate-related disease, the authors observe that people with an annual income of $3,000 or more do not die of malaria and that all world regions surpass this threshold by 2085 in most IPCC IS92 scenarios. Progressively more ambitious emissions reductions in OECD countries gradually decrease the cumulative malaria mortality if one considers only the impact side, i.e., the biophysical effects of climate change mitigation on malaria prevalence. However, if the economic effects of mitigation efforts (the slower rate of economic growth) are also taken into account then, according to the FUND model, the malaria-mortality improvements due to slower global warming will be gradually eliminated and eventually surpassed by the losses due to the reduced rate of income growth. More generally, the capacity to adapt to climate change depends on development (Tompkins and Adger, 2005; Yohe and Tol, 2002). Emission reduction policies that hamper development would increase vulnerability and could increase impacts (Tol andYohe, 2006).

18.4.3 Avoided damages

Cost-benefit analyses of greenhouse gas emission reduction (e.g., Nordhaus, 2001) necessarily estimate the avoided damages of climate change, but rarely report these. Some information can be found, however, in the Pigou tax or marginal damage costs; these values typically are reported. Tol (2005b) reviews this literature. He finds that most studies point to a marginal damage cost of less than $50/tC. He also finds a systematic, upward bias in the grey literature. For a 5% discount rate, a value used by many governments, the median estimate is only $7/tC. The marginal damage cost only gives the value of the last damage avoided, not the total avoided damage, which is seldom estimated (Corfee-Morlot and Agrawala, 2005). Nonetheless, as a first approximation of the avoided damages, one should multiple the tonnes of carbon emissions reduced with the marginal damage cost. For instance, the European Union aims to reduce 2010 emissions of carbon dioxide by some 100 million tonnes of carbon; the net present value of the avoided damage would amount to $700 million dollar, or about €1.50 per person in the EU-15.

Warren (2006) estimates total avoided impacts by piecing together impact estimates for different levels of climate change. As the impact estimates are taken from different studies, with different models and different scenarios, this method is not very reliable. Warren's (2006) study is often qualitative, while it is unclear how representative the studies she quotes are, or whether adaptation is included. Hare (2006) also offers impact estimates for various warming scenarios, but his study suffers from the same limitations as Warren's. Arnell *et al.* (2002) and Parry *et al.* (2001) use internally consistent models and scenarios, and report numbers for avoided damages, measured in millions of people at risk. Water resources and malaria dominate their results, but the underlying models do not account for adaptation and keep development at 1990 levels. In all four studies, the impact of mitigation on impacts and adaptation is ignored (see above).

Bakkenes *et al.* (2006) study the implications of different stabilisation scenarios on European plant diversity. Again, mitigation is ignored, even though biofuels and carbon plantations would substantially affect vegetation. Under the A1B scenario, in 2100, plants would lose on average 29% of their current habitat, with a range between species from 10% to 53%. Stabilisation at 650 ppm would limit this to 22% (6%-42%); at 550 ppm, 18% (5%-37%). The paper does not report the area of new habitat, but these numbers must be substantial too; the vegetation in only 1% of the area in Europe would not change. With unmitigated climate change, 9 plant species would disappear from Europe, but 8 new ones would appear. In most countries, however, the balance would be positive, with up to 145 new species in Norway and Sweden in 2100. Only in France, Greece and Italy, the number of species would fall, by up to 87 species in Greece in 2100. Stabilisation would limit the number of plant disappearances from 9 to 8 species. Jones reach a similar conclusion for the Great Barrier Reef. Unmitigated climate change would substantially damage 95% of the Reef; very stringent emission reduction would limit this to 80%.

Nicholls and Lowe (2004) estimate the avoided impact of sea level rise due to mitigation. Because sea level responds so slowly to global warming, avoided impacts are small. Nicholls and Lowe (2004) ignore the costs of emission reduction; Tol (forthcoming) shows that the bias is negligible for coastal zone impacts.

Tol and Yohe (2006), using the comprehensive impact model FUND, show that the most serious impacts of climate change can be avoided at relatively lenient stabilisation targets for greenhouse gas concentrations (e.g., 850 ppm CO_2 equivalent), and that incrementally avoided damages get smaller and smaller as one moves to more stringent stabilisation targets. For a very stringent target (e.g., 450 ppm CO_2 equivalent), climate change impacts may actually increase as the reduction of sulphur emissions may lead to warming and as abatement costs slow growth and increase vulnerability .

Overall, there are only a few studies that estimate the avoided impacts of climate change by emission reduction. Some of these studies ignore adaptation (a major bias) and mitigation costs (perhaps a major bias for some impacts) . The paucity of evidence is disappointing, as avoiding impacts is presumably a major aim of climate policy. Cost-benefit analyses of climate change implicitly estimated avoided damages, and show that these do not warrant very stringent emission reduction. Similarly, although ecosystem impacts may be large, avoidable impacts are much smaller. With few high quality studies, confidence in these findings is low. This is a clear research priority.

18.4.4 Mitigation-adaptation linkages at regional and sectoral scales

Considering the details of specific adaptation and mitigation activities at the level of regions and sectors reveals diverse linkages. In principle, four types of linkages can be distinguished: mitigation actions fostering or hindering adaptation (i.e., enhancing/undermining capacity or providing/foreclosing opportunity to cope with changing climate) and adaptation actions fostering or hindering mitigation (*i.e.*, reducing/increasing greenhouse gas emissions). In reality, the nature of the linkage (positive or negative) often depends on local conditions. Moreover, some linkages are direct, involving the same resource base (e.g., land) or stakeholders, while other linkages are indirect (e.g., effects through public budget allocations) or outright remote (e.g., shifts in global trade flows and currency exchange rates). This section focuses on direct linkages. Broader relationships between mitigation and adaptation are discussed in other parts of this chapter and in Chapter 20 related to sustainable development.

Mitigation affecting adaptation

Land use and land cover changes involve diverse and complex relationships between mitigation and adaptation. Deforestation and land conversion have been significant sources of GHG emissions for decades while often resulting in unsustainable agricultural production patterns. Abating and halting this process by incentives for forest conservation would not only avoid GHG emissions, but would also result in benefits for local climate, water resources and biodiversity.

Carbon sequestration in agricultural soils offers another obvious positive link from mitigation to adaptation. It creates an economic commodity for farmers (sequestered carbon) and makes the land more valuable by improving soil and water conservation thus enhancing both the economic and environmental components of adaptive capacity (Boehm *et al*., 2004; Butt and McCarl, 2004; Dumanski, 2004).

Afforestation and reforestation have been advocated for decades as essential mitigation options. Recent studies reveal a more differentiated picture. Competition for land by mitigation projects would increase land rents and thus commodity prices, thereby improving the economic position of landowners and enhancing their adaptive capacity. However, the implications of afforestation projects for water resources heavily depend on the geographic and climatic characteristics of the region where they are implemented. In regions with ample water resources even under a changing climate, afforestation has many positive effects, like soil conservation and flood control. However, in arid and semi-arid regions afforestation massively reduces water yields (UK FRP, 2005). This has direct and wide-ranging negative implications for adaptation options in several sectors like agriculture (irrigation), power generation (cooling towers), and ecosystem protection (minimum flow to sustain ecosystems in rivers, wetlands and on the river banks).

Bioenergy crops receive increasing attention as a mitigation option. Most studies, however, focus on technology options, costs, and competitiveness in energy markets and do not consider the implications for adaptation. For example, McDonald et al. (2006) use a global computed general equilibrium model and find that substituting switchgrass for crude oil in the USA reduces the GDP and increases the world price of cereals but they do not investigate how this might affect the prospects for adaptation in the USA and world agriculture. This limitation in scope characterizes virtually all bioenergy studies.

Another possible conflict between mitigation and adaptation might arise over water resources. One obvious mitigation option is to shift to energy sources with low GHG emissions like hydropower. In regions where hydropower potentials are still available, and also depending on the current and future water balance, this would increase the competition for water, especially if irrigation might be a feasible strategy to cope with climate change impacts in agriculture and demand for cooling water by the power sector is also significant. This reconfirms the importance of integrated land and water management strategies to ensure the optimal allocation of scarce natural resources (land, water) and economic investments in climate change mitigation and adaptation and fostering sustainable development.

Hydropower leads us to the key area of mitigation: energy sources and supply, and energy use in various economic sectors beyond land use, agriculture, and forestry. Direct implications of mitigation efforts on adaptation in the energy, transport, residential/commercial, and industrial sectors have been largely ignored so far. Yet, to varying degrees, energy is an important factor in producing goods and providing services in many sectors of the economy, as outlined in the discussion about the importance of energy to achieve the Millennium Development Goals in Chapter 2 of the WG III report. Thus reducing the availability or increasing the price of energy has inevitable negative effects on economic development and thus on the economic components of adaptive capacity. The magnitude of this effect is uncertain. Peters *et al* (2001) find that high-level carbon charges (US$200 per metric ton of carbon in 2010) affect the US agriculture modestly if they are measured in terms of consumer and producer surpluses (reductions by less than half a percent relative to baseline values) but the decline of net cash returns are more significant (4.1%) whereas the effects are rather uneven across field crops and regions. The implications of such changes for adaptation (capacity and options) remain unexplored in the literature.

The most important indirect link from mitigation to adaptation is through biodiversity, an important factor influencing human well-being in general and the coping options in particular (see MEA 2005). After assessing a large number of studies, the IPCC (2002) concluded that the implications for biodiversity of mitigation activities depend on their context, design, and implementation, especially site selection and management practices. Avoiding forest degradation implies in most cases both biodiversity (preservation) and climate (non-emission) benefits. However, afforestation and reforestation may have positive, neutral, or negative impacts depending on the level of biodiversity of the ecosystems that will be replaced. By using an optimal control model, Caparros and Jacquemont (2003) find that putting an economic value on carbon sequestered by forest management does not induce much negative influence on biodiversity but incentives to sequester carbon by afforestation and reforestation might harm biodiversity due to the over-plantation of fast-growing alien species.

These studies demonstrate the intricate linkages from climate change mitigation to adaptation, and also the relationships with other environmental concerns, like water resources and biodiversity, with profound policy implications. The land-use and forestry mitigation options in the Marrakech Accords may provide new markets for countries with abundant land areas but may alter land allocation to the detriment of the landless poor in regions where land is scarce. They present an opportunity for soil and biodiversity protection in regions with ample water resources but may reduce water yields and distort water allocation in water-stressed regions. Accordingly, depending on the regional conditions and the ways of implementation, these implications can increase or reduce the scope for adaptation to climate change by promoting or excluding effective but more expensive options due to increased land rents, by supporting or precluding forms and magnitudes of irrigation due to higher water prices, etc.

Adaptation affecting mitigation

Many adaptation options in different impact sectors are known to involve increased energy use and hence interfere with mitigation efforts if the energy is supplied from carbon-emitting sources. Two main types of adaptation-related energy use can be distinguished: one-time energy input for building large infrastructure (material and construction) and incremental energy input needed continuously to counterbalance climate impacts in providing goods and services.

The largest amount of construction work to countervail climate change impacts will be in water management and in coastal zones. The former involves hard measures in flood protection (dikes, dams, flood control reservoirs) and in coping with seasonal variations (storage reservoirs and interbasin diversions), while the latter comprises coastal defence systems (embankment, dams, storm surge barriers). Even if these construction projects reach massive scales, the embodied energy, and thus the associated GHG emissions, are likely to be merely a small portion of the total construction-related energy and emissions figures in most countries.

The magnitude and relative share of sustained adaptation-related energy input in the total energy balance depends on the impact sector. In agriculture , the input-related (CO_2 in manufacturing) and the application-related (N_2O from fields) GHG emissions might be significant if the increased application of nitrogen fertilizers offer a convenient and profitable solution to avoid yield losses. Operating irrigation works and pumping irrigation water could considerably increase the direct energy input, although, where available, utilization of renewable energy sources on-sight (wind, solar) can help avoid increasing GHG emissions.

Adaptation to changing hydrologic regimes and water availability will also require continuous additional energy input. In water-scarce regions, the increasing reuse of wastewater and the associated treatment, deep-well pumping, and especially large-scale desalination would increase energy use in the water sector (Boutkan and Stikker, 2004). Yet again, if provided from carbon-free sources like nuclear desalination (Misra, 2003; Ayub and Butt, 2005), even energy-intensive adaptation measures need not run against mitigation efforts.

Ever since the early climate impact studies, shifts in space heating and cooling in a warming world have been prominent items on the list of adaptation options, see Smith and Tirpak (1989). The associated energy requirements could be significant but the actual implications for GHG emissions depend on the carbon content of the energy sources used to provide the heating and cooling services. In most cases, it is not straightforward to separate the adaptation effects from those of other drivers in regional or national energy demand projections. For example, for the USA state of Maryland, Ruth and Lin (forthcoming) find that at least in the medium term up to 2025, climate change contributes relatively little to changes in the energy demand. Nonetheless, the climate share varies with geographical conditions (changes in heating and cooling degree days), economic (income) and resource endowments (relative costs of fossil and other energy sources), technologies, institutions and other factors. Such emissions from adaptation activities are likely to be small relative to baseline emissions in most countries and regions but more in-depth studies are needed to estimate their magnitude over the long term.

Adaptation affects not only energy use but energy supply as well. Hydropower contributed 16.3% of the global electricity balance in 2003 (IEA, 2005) with virtually zero GHG emissions. Climate change impacts and adaptation efforts in various sectors might reduce the contribution of this carbon-free energy source in many regions as conflicts among different uses of water emerge. Hayhoe *et al*. (2004) show that emissions even in the lowest IPCC scenario (B1) will trigger significant shifts in the hydrologic regime in the Sacramento River system (California) by the second half of this century and create critical choices between flood protection in the high-water period and water storage for the low-flow season. Hydropower is not explicitly addressed but will likely be affected as well. Payne *et al*. (2004) project conflicts between hydropower and stream flow targets for the Columbia River. Several studies confirm the unavoidable clashes between water supply, flood control, hydropower, and minimum streamflow (required for ecological and water quality purposes) under changing climatic and hydrologic conditions (Christensen *et al*., 1994; Vanrheenen *et al*., 2004).

Possibly the largest factor affecting water resources in adaptation is irrigation in agriculture. Yet studies in this domain tend to ignore the repercussions for mitigation as well. For example, Döll (2002) estimates significant increases in irrigation needs in two-thirds of the agricultural land that was equipped for irrigation in 1995 but she does not assess the implications for other water uses like hydropower and thus for climate change mitigation.

In general, adaptation implies that people do something *in addition* to or something *different* from what they would be doing in the absence of climate change impacts. In most cases, *additional activities* involve additional inputs: investments (protective and other infrastructure), material (fertilizers, pesticides) or energy (irrigation pumps, air conditioning) and thus may run counter to mitigation if the energy originates from GHG emitting sources. *Changing practices* in response to climate change offer more opportunities to account for both mitigation and adaptation needs. Besides the opportunities in land-related sectors discussed above, new design principles for commercial and residential buildings could simultaneously reduce vulnerability to extreme weather events and energy needs for heating and/or cooling.

We conclude that many effects of adaptation on GHG emissions and their mitigation (energy use, land conversion, agronomic techniques like increased use of fertilisers and pesticides, water storage and diversion, coastal protection) have been known for a long time. The implications of some mitigation strategies for adaptation and other development and environment concerns have been recognised recently. As yet, however, both effects remain largely unexplored. The information about mitigation-adaptation linkages at regional and sectoral level is rather scarce. Almost all mitigation studies stop at identifying the options and costs of direct emissions reductions. Some of them consider indirect effects of the implementation measures and costs on other sectors or the economy at large but do not deal with the implications for adaptation options of sectors affected by climate change. Similarly, in most cases climate impact and adaptation assessments do not go beyond taking stock of the adaptation options and estimating their costs and thus ignore possible repercussions for emissions. One understandable reason is that mitigation and adaptation studies are complex enough and expanding their scope would increase their complexity even further. The other and main reason may well be that, as indicated by the few available studies that looked at these linkages, the repercussions from mitigation for adaptation and *vice versa* are mostly marginal. Except the domains of land and water, adaptation implications of any mitigation project is small and, vice versa, the emissions generated by most adaptation activities are only small fractions of total emissions, even if emissions will decline in the future as a result of climate protection policies.

18.5 Examples of interrelationships between adaptation and mitigation

18.5.1 Stakeholder roles and spatial and temporal scales

The roles of various stakeholders cover different aspects of mitigation-adaptation linkages. Stakeholders may be characterised according to their organisational structure (e.g., public or private), level of decision-making (e.g., policy, strategic planning or operational implementation), geographic scale (e.g., local, national or international), time frame of concern (e.g., near term to long term), and function within a network (e.g., single actor, stakeholder regime or multi-level institution). Decisions might cover adaptation only, mitigation only, or link mitigation and adaptation. Relatively few public or corporate decision-makers have direct responsibility for both adaptation and mitigation. For example, adaptation might reside in a ministry of environment while mitigation policy is led by a trade, energy or economic ministry.

Stakeholders are exposed to a variety of risks, including financial, regulatory, strategic, operational, or to their reputations, physical assets, life and livelihoods (*e.g.*, Institute for Risk Management, 2002). Decision-making may be motivated by climatic risks or climate change (*e.g.*, climate-driven, climate-sensitive, climate-related). Risk is commonly defined as the probability of a consequence, while uncertainty is often taken to represent structural and behavioural factors that are not readily captured in probability distributions (*e.g.*, Stainforth *et al.*, 2005, Tol, 2003). Although this dichotomy is simplistic (see Dowie 1999), stakeholder decision making takes account of many factors (Bulkeley 2001, Clark *et al.*, 2001, Gough and Shackley 2001, Kasperson and Kasperson, 2005, Newell 2000, Pidgeon *et al*. 2003, Rayner and Malone 2001): values, preferences and motivations; awareness and perception of climate change issues; negotiation, bargaining and social norms; analytical frameworks, information and monitoring systems; and relationships of power and politics.

Faced with the deep uncertainty of climate change, stakeholders may adopt a precautionary approach with the intention of stimulating technological (if not social) change. For instance, estimates of the social cost of carbon, one measure of the benefits of mitigation, are sensitive to the choice of decision framework (including equity weighting, risk aversion, sustainability considerations, and discount rates for future damages) (Downing *et al.*, 2005; Guo *et al*, 2006; Tol, 2005b) (see WGIII chapter 3).

Criteria relating to either mitigation or adaptation, or both, are increasingly common in decision-making. For example, local development plans might screen housing developments according to energy use, water requirements and preservation of green belt (e.g., CAG Consultants and Oxford Brookes University 2004). Development agencies have begun to screen their projects for relevance to mitigation and adaptation (*e.g.*, Burton and Van Aalst, 1999; Klein, 2001; Eriksen and Næss, 2003).

Many stakeholders link climate, development and environmental policies, by, for example, linking energy efficiency (related to mitigation) to sustainable communities or poverty reduction (related to adaptation). For example, the World Bank's BioCarbon Fund and Community Development Carbon Fund include provision for buyers to ensure that carbon offsets also achieve development objectives (World Bank, 2003). The Gold Standard for CDM projects also ensures that projects support sustainable development (Carbon International). Preliminary work suggests that there may be a modest trade off between cost-effective emission reductions and the achievement of other sustainable development objectives, that is more expensive projects per emission reduction unit tend to contribute more to sustainable development than cheaper projects (Nagai and Hepburn, 2005).

Decisions are taken at different temporal, spatial and social scales. Climate change decision-making is a process of acting and learning that is likely to take place over decades if not centuries. Furthermore, it does not occur at discrete intervals but is driven by the pace of social, economic, scientific and political processes, and in response to observed and predicted climate change.
The nature of adaptation and mitigation decisions changes over time. For example, mitigation choices may initially begin with easy measures such as adoption of low-cost supply and demand-side options in the energy sector. Through successful investment in research and development, a host of low-cost alternatives should become available in the energy sector allowing for a transition to low-carbon-venting pathways. Given the current composition of the energy sector, this is unlikely to happen overnight but rather through a series of decisions over time. Initially, adaptation decisions are likely to address current climatic risks (*e.g.*, drought early-warning systems) and be anticipatory or proactive (*e.g.*, land-use regulations). With increasing climate change, autonomous or reactive actions (*e.g.*, purchasing air conditioning during or after a heat wave) are likely to increase. Decisions might also break trends, accelerate transitions and mark substantive jumps from one development or technological pathway to another (e.g., Martens and Rotmans 2002, Raskin *et al*. 2002).

Inter-relationships between adaptation and mitigation also vary according to spatial and social scales of decision making (see Figure 18.2). Mitigation and adaptation may be seen as substitutes in a policy framework at a highly aggregated, international scale: the more mitigation is undertaken, the less adaptation is necessary and vice versa. Resources devoted to mitigation might impede socio-economic development and reduce investments in adaptive capacity and adaptation projects (e.g., Kane and Shogren, 2000). This scale is inherent in the analysis of global targets (see the section on trade-offs and synergies, 18.4.2).

National and sub-national decision-making is often a mixture of policy and strategic planning. The mitigation-adaptation trade-off is problematic at this scale because the effectiveness of mitigation outlays in terms of averted climate change depends on the mitigation efforts of other major greenhouse gas emitters. However, adaptation criteria can be applied to mitigation projects or vice versa (Dang *et al*. 2003). A national policy example of synergies might be a new water law that requires metered use, enabling water companies to adjust their charges in anticipation of scarcity and conserve energy through demand-side measures. This policy would then be implemented in strategic plans by water companies and environment agencies at a sub-national level.
At the operational scale of specific projects, there may be trade-offs or synergies between adaptation and mitigation. However, the majority of projects are unlikely to have strong inter-linkages, although this remains as a key uncertainty. Certainly there are many adaptive actions that have consequences for mitigation, and mitigation actions with consequences for adaptation.

The linkages between adaptation and mitigation also link across scales (Cash and Moser, 2000; Rosenberg and Scott, 1996, Young, 2002). A policy framework is often seen as essential in driving strategic investment and operational projects (*e.g.*, Grubb, 2003, Grubb *et al.*, 2002 for technological innovation). Or, operational experience is seen as a precursor to developing sound strategies and policies (one of the motivations for early corporate experiments in carbon trading). In many cases the results of action at one scale have implications at another scale (*e.g.*, local adaptation decisions that increase greenhouse gas emissions, or national carbon taxes that change local resource use).

18.5.2 Examples of complementarities and differences

The act-then-learn perspective is extended to consider four entry points for decisions affecting adaptation and mitigation (Figure 18.3). Most linkages originate in either adaptation or mitigation, with consequences for the other. For example, a common adaptation to heat waves is to install air conditioning, which increases electricity demand with consequences for mitigation. This linkage is labelled $A \rightarrow M$, or adaptation leading to effects on mitigation. Similarly, a mitigation action to sequester carbon may affect rural livelihoods by placing a value on their management of natural resources ($M \rightarrow A$). Some actions results from the simultaneous consideration of adaptation and mitigation. These concerns may be raised within the same decision framework but without explicitly considering their trade-offs or synergies (labelled adaptation and mitigation, $A \cap M$). For example, national capacity building on climate change often includes both adaptation and mitigation in the same office. At least some analysts are concerned with the explicit trade-offs between adaptation and mitigation (labelled adaptation or mitigation, $\int(A,M)$). At the global level, for example, the costs and benefits of different mixes of climate policy and stabilisation targets might be compared.

Inter-relationships between adaptation and mitigation have been identified through examples in the published literature. Examples of these linkages and an analysis of the type of linkage can be found collated in a single source (Vulnerability Net, 2006), where the many examples have been clustered according to the type of linkage. Figure 18.3 shows a sample of the linkages documented in the literature, ordered according to the entry point and scale of decision making. Table 18.1 lists all of the types of linkages documented. The categories are illustrative, some cases occur in more than one category, or could shift over time or in different situations. For example, watershed planning is often related to managing climatic risks in using water. But if hydroelectricity is an option, then the entry point may be mitigation, and both adaptation and mitigation might be evaluated at the same time or even with explicit trade-offs.

A wide range of linkages have been documented in the literature. Many of the examples are motivated by either mitigation or adaptation, with largely unintended consequences for the other (e.g., Tol and Dowlatabadi, 2001). Most of the examples do not concern explicit trade-offs between the costs of mitigation and investment in adaptation. It appears that public decision making is taking a precautionary view of risk and accepting responsibilities for reducing emissions based on some consideration of equity.

18.6 Elements for effective implementation

This section considers the literature assessment of the previous sections with respect to its implications for policy and decision-making. It reviews the policy and institutional contexts within which adaptation and mitigation can be implemented, it discusses inter-relationships in practice, including issues of funding, and it assesses the relevance to policy and development.

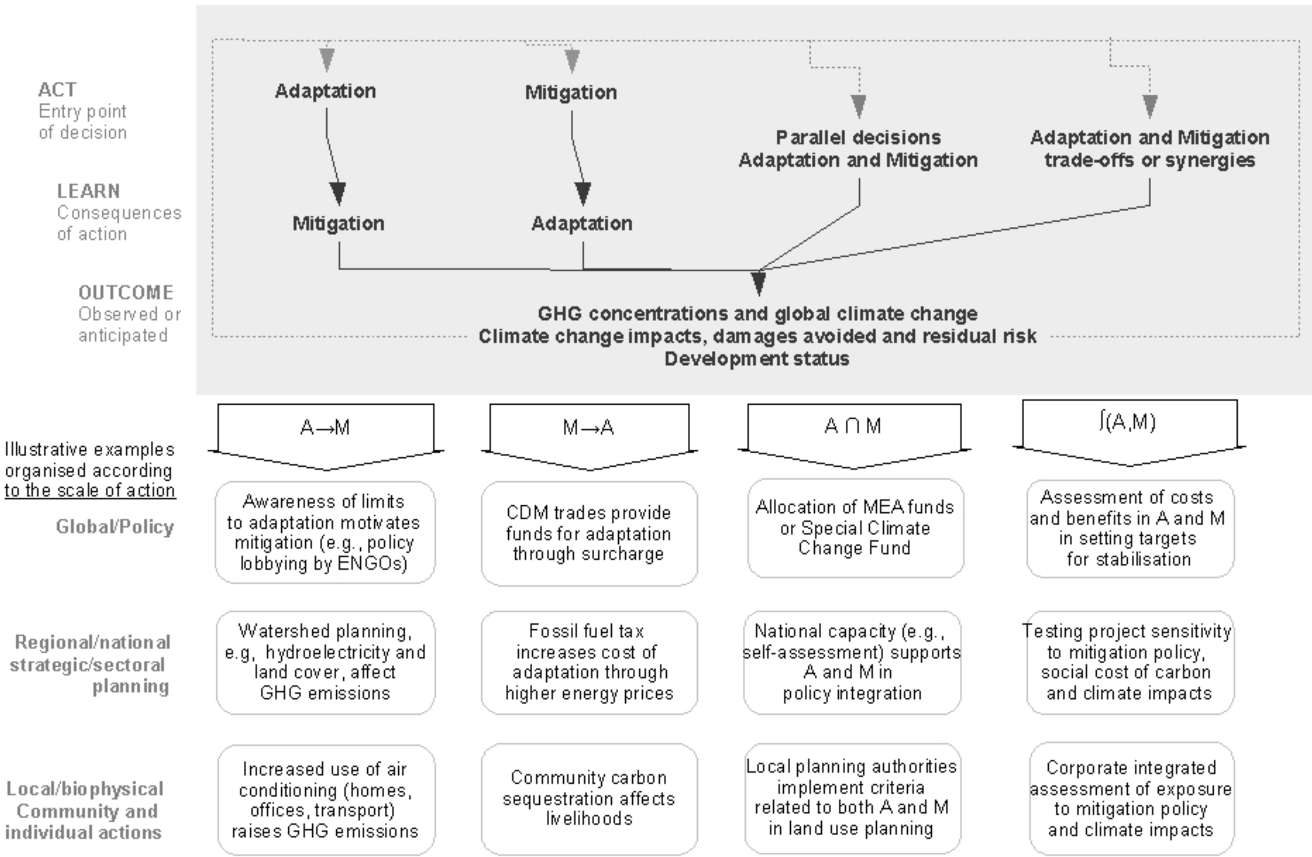

Figure 18.3: *Typology of inter-relationships between climate change adaptation and mitigation.*

18.6.1 Climate policy and institutions

As explained and illustrated in the previous sections of this chapter, effective climate policy would involve a portfolio of adaptation and mitigation actions. These actions include technological, institutional and behavioural options, the introduction of economic and policy instruments to encourage the use of these options, and research and development to reduce uncertainty and to enhance the options' effectiveness and efficiency. However, the actors involved in the implementation of these actions operate on a range of different spatial and institutional scales, representing different sectoral interests. Policies and measures to promote the implementation of adaptation and mitigation actions have therefore been targeted primarily on either adaptation or mitigation; rarely have they been given similar priority and considered in conjunction (see Section 18.5 for more detail).

On the *global scale*, the UNFCCC and its Kyoto Protocol are the principal institutional frameworks by which climate policy is developed. The ultimate objective of the UNFCCC, as stated in Article 2, is:

> "to achieve ... stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system … within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Initially, this objective was often interpreted as having relevance only or primarily to mitigation: reducing greenhouse gas emissions and enhancing sinks such that atmospheric concentrations are stabilised at a non-dangerous level. However, whether anthropogenic interference with the climate system will be dangerous or not does not only depend on the stabilisation level; it also depends on the degree to which adaptation can be expected to be effective in addressing the consequences of this interference. In other words, the greater the capacity of ecosystems and society to adapt to the potential impacts of climate change, the higher the level at which atmospheric greenhouse gas concentrations may be stabilised before climate change becomes dangerous (see also Chapter 19). Adaptation can thus complement or, in theory, substitute mitigation in meeting the ultimate objective of the UNFCCC.

The possibility of considering adaptation and mitigation as substitutes on a global scale does not feature explicitly in the UNFCCC, the Kyoto Protocol or any decisions made by the Conference of the Parties. This is so because any global agreement on substitution would, in practice, be unable to account for the diverse and at times conflicting interests of all actors involved in adaptation and mitigation (see Section 18.4.1) and for the differences in temporal and spatial scales between the two alternatives (see Section 18.5.1). Mitigation is primarily driven by international agreements and ensuing national public policies, but most adaptation is motivated by private interests of affected individuals, households and firms, and by public arrangements of impacted communities and sectors. The fact that decisions on adaptation are often made at sub-national and local levels also presents a challenge to the organisation of funding for adaptation in developing countries under the UNFCCC and the Kyoto Protocol (see Section 18.6.2).

Yet there is one way in which adaptation and mitigation are connected at the global policy level, namely in their reliance on social and economic development to provide the capacity to adapt and mitigate. Section 18.3 introduced the concept of response capacity, which can be instantiated as adaptive capacity and mitigative capacity. Response capacity is often limited by a lack of resources, poor institutions and inadequate infrastructure, amongst other factors that are typically the focus of development assistance. People's vulnerability to climate change can therefore be reduced not only by mitigating greenhouse gas emissions or by adapting to the impacts of climate change, but also by development aimed at improving the living conditions and access to resources of those experiencing the impacts, as this will enhance their response capacity.

The incorporation of development concerns into climate policy demonstrates that climate policy involves more than decision-making on adaptation and mitigation. Accordingly, Klein *et al.* (2005)

identified three roles of climate policy under the UNFCCC: (*i*) to control the atmospheric concentrations of greenhouse gases, (*ii*) to prepare for and reduce the adverse impacts of climate change and take advantage of opportunities, and (*iii*) to address development and equity issues.

Table 18.1: *Types of inter-relationships between climate change adaptation and mitigation.*

A → M	**M → A**	**A ∩ M**	**∫(A,M)**
Individual responses to climatic hazards that increase or decrease GHG emissions	More efficient energy use and renewable sources that promote local development	Perception of impacts (and limits to *A*) motivates *M*; perception of limits to *M* motivates *A*	Public sector funding and budgetary processes that allocate funding to both A and M
More efficient community use of water, land, forests	CDM projects on land use or energy use that support local economies and livelihoods	Watershed planning: allocation of water between hydroelectricity and consumption	Strategic planning related to development pathways (scenarios) to mainstream climate responses
Natural resources are managed to sustain livelihoods	Urban planning, building design and recycling with benefits for both *A* and *M*	Cultural values that promote both A and M, such as sacred forests (e.g, Satoyama in Japan)	Allocation of funding and setting the agenda for UNFCCC negotiations and funds
Tourism use of energy and water, with outcomes for incomes and emissions	Health benefits of mitigation through reduced environmental stresses	Management of socio-ecological systems to promote resilience	Stabilisation targets that include limits to adaptation (e.g., tolerable windows)
Resources used in adaptation, such as large scale infrastructure, increases emissions	Afforestation, leading to depleted water resources and other ecosystem effects, with consequences for livelihoods	Ecological impacts, with some human element, drive further releases of GHGs	Analysis of global costs and benefits of *M* to inform targets
	M schemes that transfer finance to developing countries (such as a per capita allocation) stimulate investment that may benefit *A*	Legal implications of liability for climate impacts motivates *M*	Large scale *M* (e.g., geo-engineering) with effects on impacts and *A*
	Effect of mitigation, e.g., through carbon taxes and energy prices, on resource use	National capacity building increases ability to respond to both *A* and *M*	
		Insurance spreads risk and assists with *A*; managing insurance funds has implications for *M*	
		Trade liberalisation with economic benefits (*A*) increases transport costs (*M*)	
		Monitoring systems and reporting requirements that cover indicators of both *A* and *M*	
		Management of Multi-lateral Environmental Agreements benefits both *A* and *M*	

Although climate change is not the primary reason for poverty and inequality in the world, addressing these issues is seen as a prerequisite for successful adaptation and mitigation in many developing countries. In a paper produced by a range of development agencies and international organisations, Sperling (2003) made the case for linking climate policy and development assistance, which would promote opportunities for mainstreaming considerations of climate change into development on the national, sub-national and local scales (see below).

With the first commitment period of the Kyoto Protocol ending in 2012, a range of proposals have been prepared that lay out a post-2012 international climate policy regime. The majority of these proposals focus only or predominantly on mitigation; some proposals consider adaptation and mitigation in concert. However, few proposals have been published in the peer-reviewed literature, fewer still have been appraised in terms of, for example, their effectiveness, efficiency and equity.

On the *regional scale*, climate policies and institutions do not tend to consider inter-relationships between adaptation and mitigation. In the European Union, for example, mitigation policy is conducted separately from adaptation strategies that are being developed or studied for water management, coastal management, agriculture and public health. The Alliance of Small Island States is concerned primarily with adaptation and its links with development. The Asia-Pacific Partnership on Clean Development and Climate only refers to mitigation.

The *national, sub-national and local scales* are where most adaptation and mitigation actions are implemented and where most inter-relationships may be expected. However, there is little academic literature that describes or analyses policy and institutions at these levels with respect to inter-relationships of adaptation and mitigation. The literature does provide a growing number of examples and case studies (see Section 18.5.2) but, unlike the emerging literature on global policy and institutions, it does not yet discuss policies and institutions at these levels in the light of adaptation-mitigation inter-relationships, nor does it discuss implications of potential inter-relationships on policy and institutions, or vice versa. This is an emerging research field that builds on studies that have been done for adaptation or for mitigation. For example, the AMICA project (Adaptation and Mitigation: an Integrated Climate Policy Approach) aims at identifying synergies between adaptation and mitigation for selected cities in Europe.

More common and also relevant to climate policy and institutions on national, sub-national and local scales are studies that investigate the potential of mainstreaming adaptation and mitigation actions into development planning and ongoing sectoral decision-making. Mainstreaming aims at ensuring the long-term sustainability of investments, as well as at reducing the sensitivity of development activities to both today's and tomorrow's climate (Huq *et al.*, 2003; Agrawala *et al.*, 2005). Mainstreaming is seen as making more efficient and effective use of financial and human resources than designing, implementing and managing climate policy separately from ongoing activities. By its very nature, energy-based mitigation (*e.g.*, fuel switch and energy conservation) can be effective only when mainstreamed into energy policy. For adaptation, however, this link has not appeared as self-evident until recently (see Chapter 17). Mainstreaming is based on the premise that human vulnerability to climate change is reduced not only when climate change is mitigated or when successful adaptation to the impacts takes place, but also when the living conditions for those experiencing the impacts are improved (Huq and Reid, 2004).

Although mainstreaming is most often discussed with reference to developing countries, it is just as relevant to industrialised countries. In both cases it requires the close linking, if not integration, of climate policy and sectoral and development policies. The institutional means by which such linking and integration is attempted or achieved vary from location to location, from sector to sector, as well as across spatial scales. For developing countries, the UNFCCC could play a part in facilitating the successful integration and implementation of adaptation and mitigation in sectoral and development policies. Klein *et al.* (2005) see this as a possible fourth role of climate policy, in addition to the three presented earlier in this section. To facilitate mainstreaming would require increasing awareness and understanding amongst decision-makers and managers, and creating mechanisms and incentives for mainstreaming. It would not require developing synergies between mitigation and adaptation *per se*, but rather between building adaptive and mitigative capacity, and thus with development (see Section 18.3.4). This new role of climate policy highlights the importance of involving a greater range of actors in the planning and implementation of adaptation and mitigation, including sectoral, sub-national and local actors (see Section 18.5.1). This is reflected in the respective roles of institutions at these levels.

According to Keohane (Keohane 1988) institutions are "not only discrete organisations (e.g., government agencies), but also more generally, set of rules, processes or practices that prescribe behavioural role for actors, constrain activity, and shape expectations". Successful implementation of climate policy is inextricably linked to institutional capacity. (OECD, 2003). Institutional capacity can meet both sustainable development priorities as well as climate policy actions (Michel, 2004). Outside the UNFCCC context, bilateral, regional and multilateral institutions dealing with climate change issues can help mainstream climate change in development agenda more and more specifically enhance technology transfer and flow of resources to developing countries. (OECD, 2003) Climate policy has largely evolved in a separate cluster with little interactions between the scientific and development world but there more and more interactions refer to the various steps of the various IPCC reports. In developed countries, bridging the divide means linking climate to issues such as energy security, urban air pollution or national security issues.

In developing countries, the link can be made through "mainstreaming" climate into development priorities such as poverty reduction, health priorities, and provision of critical services such as energy. (Beg *et al.*, 2002). For developing countries, institutional capacity and governance are critical in order to support climate policy actions (OECD, 2003). It is becoming increasingly clear that the wide array of decisions may not be reached under the UNFCCC umbrella alone and international, regional and national choices of climate prevention are possible options through which effective decision making can be channelled. Various initiatives which emerged from the Rio process and related outcomes such as Agenda 21, World Summit on Sustainable Development, the Millennium Development Goals and so on offer tremendous opportunities along with bilateral and multilateral development institutions to coherently formulate climate policies and build synergies.

Organisations such as the World Trade Organisation and the European Union can, through specific mechanisms, integrate environmental policy into their economic rationales. The agricultural sector, particularly industrial agriculture and the use of strong fertiliser accounts for the production of emissions such as methane and nitrous oxide. However, whilst many governments under the UNFCCC are advocating a less-fossil fuel dependent pathway, they are also taking on agricultural trade policies that would amount to vast increases in energy demands of both agricultural production and distributions systems.

Alongside the need to use existing mechanisms within the WTO to integrate climate and economic considerations, there is also a considerable need to address contradictions between policies relevant to the reduction of greenhouse gas emissions and agricultural trade policies. Energy remains a quintessential input in agro-processing, transportation and packaging, and the combined effect of increases in energy consumption in the agricultural sector and impacts of agricultural trade policies are not thought through within the broad parameters of climate change. Other sectors such as forestry can be climate proofed and thus looked at within specific mechanisms of the EU from an environmental/climate perspective. The main legislative mechanism that deals with forests tends to be linked to the Common Agricultural Policy (CAP). Policies within the CAP offer some support for agricultural and silvicultural activities that help increase carbon sequestration A recent addition to the EU's effort is the establishment of a Working Group on Forest Sinks within the European Climate Change Programme (ECPP).

In Africa, countries belonging to the same regional economic groupings can identify projects that have net adaptation and mitigative benefits. In the water sector, river basin institutions such as the Senegal River Basin Authority (Organisation pour la Mise en Valeur du Fleuve Senegal, OMVS, the Nile Basin Initiative). Projections under SRES scenarios note that by 2025 roughly 370 million people in Africa will experience water-stress while likely increases in precipitation will mean that 100 million people will see a decrease in water stress by 2055 (Arnell, 2004). Scenarios used by Greco and al show that over the next 30-60 years there would be a significant reduction of water in most of the large rivers in the Sahelian region (http://www.grida.no/climate/ipcc/regional/019.htm). Regional adaptation plans to curtail climate change and variability have received little attention. Studies have predicted reduction in water supply in most of the large rivers of the Sahel thus affecting vital sectors such as energy and agriculture both of which are dependent on water availability for hydroelectric power generation and agricultural production. It is worth noting that 17 countries in West Africa share 25 trans-boundary rivers and a high proportion of countries within the region tend to have a water dependency ratio of 90%. (Denton *et al*, 2002) Water resources and watershed management in trans-boundary ecosystems are all possible ways in which countries in West Africa can co-operate on a regional basis to build institutional capacity, strengthen regional networks and institutions to encourage co-operation, flow of information and transfer of technology. The construction of the Manantali dam in Mali as part of the Senegal River Basin Initiative is able to produce hydropower electricity and enable riparian communities to practice irrigation agriculture especially since Senegal and Mauritania remain highly dependent on agriculture and suffer deficits in staple cereal crops. These initiatives have global sustainable development benefits since they are able to offer both adaptation and mitigative benefits as well as accelerate economic development of countries sharing the river (namely Senegal, Mali and Mauritania) (Venema, *et al*, 1997)

Regional co-operation could create “win-win” opportunities in both economic integration and addressing the adverse effects of climate change (Denton *et al*, 2002). Organisations such as New the Partnership for Africa’s Development (NEPAD) and the African Ministerial Conference on the Environment (AMCEN) conducted a number of consultative process in order to prepare an Environmental Action Plan for the Implementation of the Environment Initiative of NEPAD. One of the proposed developing projects is to evaluate synergistic effects of adaptation and mitigation activities (UNEP, 2003). Projects such as on farm and catchments management of carbon management with sustainable livelihood benefits are envisaged. Organisations such as the West African Monetary Union (UEMOA -WAEMU) are actively engaged in energy development to address the perennial problem of energy poverty in the continent tend to focus on how to exploit mechanisms such as the Clean Development Mechanisms in order to mitigate against present and future emissions, especially with the use of renewables. UEMOA countries are vulnerable to drought and desertification and while mitigation may not be their main concern it does offer opportunities to reduce negative impacts that are pervasive in deforestation and land use change. Equally, linkages between the UNFCCC and the UN Convention to Combat Desertification (UNCCD) offer opportunities to exploit both adaptation and mitigation synergies within the context of increasing sustainable livelihoods option and environmental management. This is perhaps even more relevant to current sub-regional institutional set-up with specific action plans to address desertification.[1] Institutional arrangements are a viable option for mainstreaming climate change into development and regional objectives and thus build synergy through the formulation of coherent policies.

[1] These organisations are mainly the Arab Maghreb Union (AMU) in Northern Africa, the Inter-Governmental Authority on Development (IGAD) in Eastern Africa, the Southern African Development Community (SADC) in the South, the Economic Community of Western African Countries (CEDEAO) and Inter-Permanent Committee for Drought Control in the Sahel (CILSS) for the West, and the Economic Community of Central African Countries (CEMAC) in central Africa

From a national perspective, effective implementation of climate change adaptation and mitigation is dependent on support from local NGOs, private sector i.e. industries, civic groups, the public and local government authorities. Market based policy instruments which provide incentives such as pollution taxes and different types of tradeable pollution permits have been successfully implemented in developed countries. In the Niayes region (central Senegal), the government has sought to promote irrigation practices and reduce dependence on rain-fed agriculture with the planting of dense hedges to act as windbreaks. These have enhanced agricultural productivity. Windbreaks have been effective in combating soil erosion and desiccation and have also provided much needed fuelwood for cooking, thus reducing the drudgery that women and young girls face by travelling long distances in a rapidly urbanising area in the search of wood. The windbreaks have carbon sequestration benefits but, most of all, they have helped to intensify agricultural production especially with commercial products, thus boosting the economic livelihoods of poor communities. Thus, what started off as an adaptation strategy has had huge integrated development benefits by easing deforestation and reducing carbon emission as well as addressing gender and livelihood aspirations. (Seck, *et al* 2005).

The use of market based incentives such as taxes, subsidies and in the case of India tax credits and financial assistance has opened up the electricity and allowed the private sector to come in thus resulting in a "wind energy boom" (Sawin, J *et al* 2004) . Renewable energy sources such as biogas and wind on a large scale in India have tremendous mitigation and adaptation net benefits as well as addressing sustainable development priorities of communities. Equally, deliberate policies that create incentives for the uptake of biofuels and energy efficiency programmes in Brazil have considerably reduced carbon emissions (Pew Center 2002). Although a number of these programmes are not designed to serve the synergistic twin effect of adaptation and mitigation it is clear that they do present some net adaptation and mitigation benefits. In addition, the private sector is also increasingly becoming involved in environmental governance. Transnational corporations are also increasingly drawn into partnerships and networks as a way of managing the global environment.

18.6.2 Inter-relationships in practice

In practice, mitigation and adaptation can be included in climate change strategies, polices and measures at different levels, involving different stakeholders. For example at the multi-country, regional level, the European Union previously emphasised policies to focus on reducing GHG emissions in line with Kyoto targets. But, they are increasingly acknowledging the need to deal with the consequences of climate change. In 2005, the European Commission launched the 2nd Phase of the European Climate Change Programme (ECCP), which for the first time addresses includes impacts and adaptation as one of its working groups (EEA 2005). They recognise the value of 'win-win' strategies which address climate change impacts but also contribute to mitigation objectives (EEA, 2005)

At the national level there are also examples, including the United Kingdom, which is tackling climate change through its UK Climate Change Programme (DETR, 2000), including adaptation and mitigation policy issues. Further, the UK is tackling adaptation through the Adaptation Policy Framework (APF, 2005), the UK Climate Impacts Programme (UKCIP) and a Cross Regional Research Programme, a cross-governmental initiative being led by DEFRA. Malta identified in its 1st National Communication to the UNFCCC a range of 'win-win' adaptation options, including efficiency in energy production, improving farming, afforestation (Ministry for Rural Affairs and the Environment Malta 2004). The Czech Republic has agreed to give priority to 'win-win' measures, due to financial constraints (EEA, 2005).

At the sub-national, regional or city level activities are taking place including efforts in the UK's

Office of the Deputy Prime Minister which released planning policy and advice to be taken into account by regional planning bodies. The purpose of the policy is to guide the preparation of regional spatial strategies by the Mayor of London in relation to the spatial development strategy of London, and by local planning authorities in the preparation of local development documents (ODPM 2005). It includes advice to planners on how to integrate climate change mitigation and adaptation into their policy planning decisions. Other examples of projects which incorporate 'climate proofing' include the Cities for Climate Protection (CCP) Campaign, a worldwide movement of local governments working together under the initiation of the International Council for Local Environmental Initiatives (ICLEI) to reduce greenhouse gas emissions, improve air quality, and enhance urban sustainability. Local governments following this programme develop a baseline of their emissions, set targets and agree on an action plan to reach the targets through a sustainable development approach focusing on local quality of life, energy use and air quality (ICLEI 2006). For example, the Southampton City Council developed a climate change strategy in conjunction with its air quality strategy and action plan, seeing close links between the two. The strategy includes measures for the council and partners to reduce net emissions of greenhouse gases and other pollutants through integrated energy systems and continued air quality monitoring. The mitigating measures are supported by improved management of the likely impacts of future climate change and the impacts on air quality through better planning and adaptation, such as coastal defence, transport infrastructure, planning and design, and flood risk mapping. (Southampton City Council 2004).

At the sectoral level examples include the built environment through encouraging energy efficiency. The UK Government encourages an integrated approach to ensure that adaptation initiatives do not increase energy demands and therefore conflict with greenhouse gas mitigation measures. Adaptation measures would include decisions about siting new settlements, and not creating an unsustainable demand for water resources by taking into account possible changes in seasonal precipitation (ODPM, 2004).

At the project level, a number of examples illustrate both mitigation as well as adaptation co-benefits. As part of decentralised energy systems in India, small biomass gasifier based power plants will be linked to energy services and micro industries, all owned by village cooperatives. A biogas project in Nepal aims to develop biogas use as a commercially viable, market-oriented industry in Nepal by bringing fuel for cooking and lighting to rural households. Other examples are a compact fluorescent light bulbs project for low-income households in South Africa and a Soil Conservation Project in Moldova (Development Alternatives Group, 2006).

The Convention on Biological Diversity (CBD) has acknowledged the potential win-wins between biodiversity management, and mitigation and adaptation to climate change.

There is particular scope for this in large-scale regional biodiversity programmes such as the Mesoamerican Biological Corridor Project which due to its size, reforestation and avoided deforestation aims can help to mitigate climate change through the creation of carbon sinks, livelihood benefits for local communities can help to increase their resilience to adapt to the impacts of climate change. In addition, the creation of large biological corridors will help ecological communities migrate and adapt to changing environmental conditions (CBD 2003).

A special role can be played by international funding agencies and climate change funds. Thus, for example, the World Bank's BioCarbon Fund and Community Development Carbon Fund provide financing for projects, such as reforestation to conserve and protect forest ecosystems, community afforestation activities, mini and micro-hydro and biomass fuel projects (World Bank). These types of project are focused specifically at extending carbon finance to poorer countries and contribute not only to the mitigation of climate change but also to reducing rural poverty and improving sustainable management of local ecosystems, thereby enhancing adaptive capacity. Similarly, the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP) have been funding both mitigation as well as adaptation activities over the years.

18.6.3 Relevance to policy and development

As climate change policies and measures begin to be implemented at different scales, the need to include an assessment of both mitigation as well as adaptation as appropriate response options, while looking for synergies, has begun at various levels by different actors and stakeholders. Incorporating both mitigation as well as adaptation as part of climate change response options is particularly relevant for development policy which requires climate change responses to be included in larger economic and social policy contexts.

18.7 Uncertainties, unknowns, and priorities for research

Many of the inter-relationships between adaptation and mitigation have been described in previous assessments of climate policy, and the literature is rapidly expanding. Still, well-documented studies at the regional and sectoral level are lacking. Mitigation and adaptation studies tend to focus only on their primary domains, and few studies analyse the secondary consequences (e.g., of mitigation on impacts and adaptation options or of adaptation actions on greenhouse gas emissions and mitigation options). Experiences with climate change adaptation is relatively recent and large-scale and global actions, such as insurance, an adaptation protocol or liability and compensation, have not been tested.

Learning from the expanding case experience of linkages is a priority. Reviews, syntheses and meta-analyses should become more common in the next few years. An analytical and institutional framework for monitoring the inter-relationships and organising periodic assessments should be developed. At present, no organisation appears to have a lead role in this area. Protocols for action should be compared. The experience of the land use/land cover programme would be insightful (e.g., Geist and Lambin 2002). Effective institutional development, use of financial instruments, participatory planning and risk management strategies are areas for learning from the emerging experience (Klein *et al.*, 2005).

A key research need is to document which stakeholders link adaptation and mitigation. Decisions oriented toward either adaptation or mitigation might be extended to evaluate unintended consequences, to take advantage of synergies or explicitly evaluate trade-offs. Yet, the constraints of organisational mandates and administrative capacity, finance, and linking across scales and sectors (*e.g.*, Cash and Moser, 2000) may outweigh the benefits of integrated decision making. Formulation of policies that support renewable energy in developing countries, an example of a major link between adaptation and mitigation, is likely to meet fiscal, market, legal, knowledge and infrastructural barriers that limit uptake.

The effects on specific social and economic groups should be further documented. For example, development of hyrdro-electricity may reduce water availability for fish farming and irrigation of home gardens, potentially adversely affecting the food security of women and children (Andah *et al.* 2004; Hirsch and Wyatt, 2004). Or, linking carbon sequestration and community development could generate new opportunities for women and marginal socio-economic groups, but this will depend on many local factors and needs to be evaluated with empirical research.

The links between a broad climate change response capacity, specific capacities to link adaptation and mitigation, and actual actions are poorly documented. Testing and quantification of the relationship between capacities to act and actual action is needed, taking into account sectoral planning and implementation, the degree of vulnerability, the range of technological options, policy instruments, and information including experience of climate change.

A clear, comprehensive analytical framework for evaluating the links between adaptation and mitigation is lacking. Decision frameworks relating adaptation and mitigation (separately or conjointly) should be tested against the roles and responsibilities of stakeholders at all levels of action. Global optimising models may influence some decisions, while experience at the project level is important to others. The suitability of integrated assessment models should be evaluated for exploring multiple metrics, discontinuities and probabilistic forecasts (Mastrandrea and Schneider, 2001, 2004; Schneider 2003). Hybrid approaches to integrated assessments across scales (top down and bottom up) should be further developed (Wilbanks and Kates, 2003). Representations of risk and uncertainties need to be related to decision frameworks and processes (Dessai *et al.,* 2004; Kasperson and Kasperson, 2005; Lorenzoni *et al*., 2005). Climate risk, current and future, is only one aspect of adaptation-mitigation decision-making; the relative importance and effect of other drivers needs to be understood.

The magnitude of unintended consequences is uncertain. The few existing studies (e.g., Dang *et al*. 2003) indicate that the repercussions from mitigation for adaptation and vice versa are mostly marginal. The effects on demand or total emissions are likely to be a small fraction of the global baseline. However, in some domains, such as water and land markets, and in some locales, the linkages might affect local economies. Quantitative evaluation of direct trade-offs is missing: the metrics and methods for valuation, existence of thresholds in local feedbacks, behavioural responses to opportunities, risks and adverse impacts, documentation of the baseline and project scenarios, and scaling up from isolated, local examples to systemic changes are part of the required knowledge base.

At a global or international level, defining a socially, economically and environmentally justifiable mix of mitigation, adaptation and development remains a research need. The extent to which targets that are set globally are consistent with national or local mixes of strategies requires a concerted effort. The distributional effects would be an important factor in evaluating tolerable windows and trade-offs between adaptation and mitigation. The lack of high quality studies of the benefits of mitigation, the social cost of carbon, limits confidence in setting targets for stabilisation. A systematic assessment with a formal risk framework that guides expert judgement and grounded case studies, and interprets the sample of published estimates, is required if policy makers wish to identify the benefits of climate policy (e.g., Downing *et al*. 2005). While global integrated assessment models are relatively well-developed, they can only provide approximate estimates of quantitative linkages at a highly aggregated scale.

The relationship between development paths and adaptation-mitigation inter-relationships requires further research. Unintended consequences, synergies and trade-offs might be unique to some development paths; equally, they might be possible in many different paths. Existing scenarios of development paths, such as the SRES, are particularly inadequate in framing some of the major determinants of vulnerability and adaptation (Downing, *et al*., 2003). For example, global scenarios of food security are lacking in recent years (Downing and Ziervogel , 2005). Few if any reference scenarios explicitly frame issues related to adaptation-mitigation linkages (e.g., from the extent to which a global decision maker makes optimising judgements to the institutional setting for local projects to exploit synergies). While the direct energy input in large infrastructure projects may be small, including a shadow price for climate change externalities, may shift adaptation portfolios. An assessment of actual shifts in energy demand and ways to reduce emissions is desirable. Most integrated assessments are at the large scale of regions to world-views, although local dialogues are beginning to explore synergies (Munasinghe and Swart, 2005).

The feasibility and outcome of many of the inter-relationships depend on local conditions and management options. A systematic assessment and guidance for mitigating potentially adverse effects would be helpful. The nature of links between public policy and private action at different scales and prospects for mainstreaming integrated policy are worth evaluating. Many of the consequences depend on environmental processes that may not be well understood, for example, resilience of systems to increased inter-annual climate variability and long-term carbon sequestration in agro-forestry systems.

References

Adger, W.N., T.A. Benjaminsen, K. Brown, and H. Svarstad, 2001: Advancing a Political Ecology of Global Environmental Discourses. *Development & Change*, **32**(4)

Adger, W.N., N. Brooks, M. Kelly, S. Bentham, and S. Eriksen, 2004: *New Indicators of Vulnerability and Adaptive Capacity. Technical Report 7.*, Tyndall Centre for Climate Research., Norwich, UK.

Adger, W.N., T.P. Hughes, C. Folke, S.R. Carpenter, and J. Rockstram, 2005: Social- Ecological Resilience to Coastal Disasters. *Science*, **309**(5737), pp. 1036.

Adger, W.N., S. Huq, K. Brown, D. Conway, and M. Hulme, 2003: Adaptation to climate change in the developing world. *Progress in Development Studies*, **3**(3), pp. 179.

Adger, W.N., and K. Vincent, 2005: Uncertainty in adaptive capacity. *Comptes Rendus Geoscience*, **337**(4), pp. 399-410.

Agrawal, A., 2001: Common property institutions and sustainable governance of resources. *World Development*, **29**(10), pp. 1649-1672.

Agrawala, S. (ed.), 2005: *Bridge Over Troubled Waters - Linking Climate Change and Development*. Organization for Economic Cooperation and Development, Paris, France, 153pp.

Altieri, M.A., 1999: Applying Agroecology to enhance the productivity of Peasant farming systems in Latin America. *Environment, Development and Sustainability*, **1**(3-4), pp. 197-217.

Andah, W., N. van de Giesen, A. Huber-Lee, and C. Biney, 2004: Can we maintain food security without losing hydropower? The Volta Basin. In: *Climate Change in Contrasting River Basins*. CABI Publishing, UK

Andersen, B., 1998: The evolution of technological trajectories 1890-1990. *Structural Change and Economic Dynamics*, **9**(1), pp. 5-34.

Ansuategi, A., and M. Escapa, 2002: Economic growth and greenhouse gas emissions. *Ecological Economics*, **40**(1), pp. 23-37.

Arnell, N., M.G.R. Cannell, M. Hulme, R.S. Kovats, J.F.B. Mitchell, R. Nicholls, M. Parry, M. Livermore, and A. White, 2002: The consequences of CO2 stabilization for the impacts of climate change. *Climatic Change*, **53**, pp. 413-446.

Arthur, W.B., 1989: Competing technologies, increasing returns, and lock-in by historical events. *The Economic Journal*, **99**(394), pp. 116-131.

Ayub, M.S., and W.M. Butt, 2005: Nuclear desalination: harnessing the seas for development of coastal areas of Pakistan. *International Journal of Nuclear Desalination*, **1**, pp. 477- 485.

Azar, C., and H. Dowlatabadi, 1999: A review of technical change in assessment of climate policy. *Annual Review of Energy and the Environment*, **24**(1), pp. 513-545.

Bakkenes, M., B. Eickhout, and R. Alkemade, 2006: Impacts of different climate stabilization scenarios on plant species in Europe. *Global Environment Change*, **16**, pp. 19-28.

Banuri, T., G. Hyden, C. Juma, and M. Rivera, 1994: *Sustainable Human Development: From Concept to Operation.*, United Nations Development Programme, New York.

Banuri, T., J. Weyant, G. Akumu, A. Najam, L. Pinguelli Rosa, S. Rayner, W. Sachs, R. Sharma, and G. Yohe, 2001: Setting the Stage: Climate Change and Sustainable Development. In: *Climate Change 2001: Mitigation, Report of Working Group III, Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, U.K., pp. 75-110.

Barnett, J., 2001: *The Meaning of Environmental Seruirity, Ecological Politics and Policy in the New security Era.* Zed Books, London.

Baron, J., and M. Spranca, 1997: Protected values. *Organizational Behaviour and Human Decision Processes*, **70**(1), pp. 1-16.

Beg, N., J. Corfee Morlot, O. Davidson, Y. Arfrane-Okesse, L. Tyani, F. Denton, Y. Sokona, J.P. Thomas, E.L. Rovere, J. Parikh, K. Parikh, and A. Rahman, 2002: Linkages between climate change and sustainable development. *Climate Policy*, **2**(2-3), pp. pp. 129-144.

Berkhout, F., 2002: Technological regimes, path dependency and the environment. *Global Environment Change*, **12**, pp. 1-4.

Berritella, M., A. Bigano, R. Roson, and R.S.J. Tol, forthcoming: A general equilibrium analysis of climate change impacts on tourism. *Tourism Management*
Boehm, M., B. Junkins, R. Desjardins, S. Kulshreshtha, and W. Lindwall, 2004: Sink potential of Canadian agricultural soils. *Climatic Change*, **65**, pp. 297-314.
Bosello, F., R. Roson, and R.S.J. Tol, forthcoming: Economy-wide estimates of the implications of climate change: Human health. *Ecological Economics*
Boutkan, E., and A. Stikker, 2004: Enhanced water resource base for sustainable integrated water resource management. *Natural Resources Forum*, **28**(2), pp. 150-154.
Brooks, N., W. Neil Adger, and P. Mick Kelly, 2005: The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, **15**, pp. 151 - 163.
Burton, I., and M. van Aalst, 1999: *Come Hell or High Water: Integrating Climate Change Vulnerability and Adaptation into Bank Work.* World Bank, Washington, D.C., USA, 60pp.
Butt, T.A., and B.A. McCarl, 2004: Farm and forest sequestration: Can producers employ it to make some money? *Choices*, **Fall 2004**, pp. 27-33.
CAG Consultants and Oxford Brookes University, 2004: *Planning Response to Climate Change: Advice on Better Practice.* Office of the Deputy Prime Minister, London.
Caparros, A., and F. Jacquemont, 2003: Conflicts between biodiversity and carbon sequestration programmes: economic and legal implications. *Ecological Economics*, **46**(1), pp. 143-157.
Carbon International, no date: *The Gold Standard: Premium Quality Carbona Credits.*
Cash, D.W., and S. Moser, 2000: Linking global and local scales: Designing dynamic assessment and management processes. *Global Environment Change*, **10**(2), pp. 109- 120.
CBD, 2003: *Climate Change and Biodiversity. Executive Summary of the Report on the Interlinkages Between Biodiversity and Climate Change.* CBD Technical Series.
Christensen, N.S., A.W. Wood, N. Voisin, D.P. Lettenmaier, and R.N. Palmer, 2004: The effects of climate change on the hydrology and water resources of the Colorado River Basin. *Climatic Change*, **54**, pp. 269-293.
Cifuentes, A.L., V.H. Borja-Aburto, N. Gouveia, G. Thurston, and D.L. Davis, 2001: Hidden health benefits of greenhouse gas mitigation. *Science*, **293**(5533), pp. 1257-1259.
Clark, W.C., N. Dickson, and *et al*., 2001: *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion, and Acid Rain.* MIT Press, Cambridge.
Cohen, S., D. Demeritt, J. Robinson, and D. Rothman, 1998: Climate Change and sustainable development: Towards dialogue. *Global Environmental Change*, **8**(4), pp. 341-373.
Corfee-Morlot, J., and S. Agrawala, 2004: *The Benefits of Climate Change Policies.* OECD, Paris.
Dalal-Clayton, B., 2003: *The MDGs and sustainable development: the need for a strategic approach.*, IIED, London, 73-91pp.
Dang, H., A. Michaelowa, and D. Tuan, 2003: Synergy of adaptation and mitigation strategies in the context of sustainable development: the case of Vietnam. *Climate Policy*, **3S1**, pp. S81-S96.
de Klerk, G.J., and J.J.D. Havenga, no date: *SME networks and clusters and their impact on on economic growth: An exploratory overview of Africa*.
Denton, F, Y. Sokona and J. P. Thomas, 2002: *Climate change and sustainable development strategies in the making: what should west African countries expect?* OECD, Paris, p4.
Dessai, S., W.N. Adger, M. Hulme, J. Turnpenny, J. Kohler, and R. Warren, 2004: Defining and experiencing dangerous climate change. *Climatic Change*, **64**(1-2), pp. 11-25.
Development Alternatives Group, 2006: *Adaptation to Climate Change through Mitigation Opportunities.*
Doll, P., 2002: Impact of climate change and variability on irrigation requirement: A global perspective. *Climatic Change*, **54**(269-293).
Dowie, J., 1999: Against risk. *Risk Decision and Policy*, **4**(1), pp. 57-73.
Downing, T.E., D. Anthoff, R. Butterfield, M. Ceronsky, M. Grubb, J. Guo, C. Hepburn, C. Hope, A.

Hunt, A. Li, A. Markandya, S. Moss, A. Nyong, R.S.J. Tol, and P. Watkiss, 2005: *Scoping uncertainity in the social cost of carbon; Final project report. Social Cost of Carbon: A Closer Look at Uncertainty (SCCU).* Defra, Oxford:SEI.
Downing, T.E., M. Munasinghe, and J. Depledge, 2003: Introduction to special supplement on climate change and sustainable development. *Climate Policy*, **3**(1), pp. 3-8.
Downing, T.E., and G. Ziergvogel, 2005: *Food system scenarios.* Stockholm Environment Institute, Stockholm.
Dumanski, J., 2004: Carbon sequestarion, soil conservation, and the Kyoto Protocol: Summary of implications. *Climatic Change*, **65**, pp. 255-261.
Dupuy, D., 1997: Technological change and environmental policy: The diffusion of environmental technology. *Growth and Change*, **28**(1), pp. 49-66.
EEA, 2005: *Vulnerability and adaptation to climate change in Europe. EEA Technical Report No. 7/2005.* EEA, Copenhagen.
Eriksen, S., and L.O. Næss, 2003: *Pro-Poor Climate Adaptation: Norwegian Development Cooperation and Climate Change Adaptation—An Assessment of Issues, Strategies and Potential Entry Points.* Centre for International Climate and Environmental Research Oslo, University of Oslo, Norway, viii+75 pp.pp.
Fankhauser, S., and R.S.J. Tol, 2005: On climate change and economic growth. *Resource and Energy Economics*, **27**, pp. 1-17.
Fisher, B.S., G. Jakeman, H.M. Pant, M. Schwoon, and R.S.J. Tol, forthcoming: CHIMP: A simple population model for use in integrated assessment of global environmental change. *Integrated Assessment Journal*
Foray, D., and A. Grubler, 1996: Technology and the environment. *Technological Forecasting and Social Change*, **53**(1), pp. 3-13.
Geels, F.W., and W. Smit, 2000: Failed technology futures: pitfalls and lessons from a historical survey. *Futures*, **32**(9-10), pp. 867-885.
Geels, G.W., 2004: From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, **33**(6-7), pp. 897-920.
Geels, G.W., 2005: Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological Forecasting and Social Change*, **72**(6), pp. 681-696.
Geist, H.J., and E.F. Lambin, 2002: Proximate causes and underlying driving forces of tropical deforestation. *Bioscience*, **52**(2), pp. 143-150.
Goklany, I.M., 2005: Integrating strategies to reduce vulnerability and advance adaptation, mitigation, and sustainability. *forthcoming*
Grothmann, T., and A. Patt, 2005: Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change*, **15**(3), pp. 199- 213.
Grubb, M., 2003: The economics of the Kyoto Protocol. *World Economics*, **4**(3), pp. 143-189.
Grubb, M., J. Kohler, and D. Anderson, 2002: Induced technological change in energy and environmental modelling: Analytic approaches and policy implications. *Annual Review of Energy & the Environment*, **21**(1), pp. 271-308.
Grubler, A., 2000: *Technology and Global Change.* Cambridge University Press, Cambridge.
Guo, J., C. Hepburn, R.S.J. Tol, and D. Anthoff, 2006: Discounting and the social cost of carbon: A closer look at uncertainty. *Environmental Science and Policy*, **9**(3), pp. 205- 216.
Haddad, B., 2005: Ranking the adaptive capacity of nations to climate change when socio- political goals are explicit. *Global Environmental Change*, **15**(165-176)
Handmer, J.W., S. Doers, and T.E. Downing, 1999: Societial vulnerability to climate change and vulnerability. *Mitigation and Adaptation Strategies for Global Change*, **4**, pp. 267- 281.
Hare, B., 2006: Relationship between increases in global mean temperature and impacts on ecosystems, food production, water and socio-economic systems. In: *Avoiding Dangerous Climate*

Change. Cambridge University Press, Cambridge, U.K., pp. 177- 185.
Hayhoe, K., D. Cayan, and C.B. Field, 2004: Emissions pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences of the United States of America*, **101**(34), pp. 12422-12427.
Hirsch, P., and A. Wyatt, 2004: Negotiating local livelihoods: Scales of conflict in the Se San River Basin. *Asia Pacific Viewpoint*, **45**(1), pp. 51-68.
Howe, J., and P. Wheeler, 1999: Urban food growing: The experience of two UK cities. *Sustainable Development*, **7**(1), pp. 13-24.
Huq, S., A. Rahman, M. Konate, Y. Sokona, and H. Reid, 2003: *Mainstreaming Adaptation to Climate Change in Least Developed Countries (LDCs).* International Institute for Environment and Development, London, U.K., 40pp.
Huq, S., and H. Reid, 2004: Mainstreaming adaptation in development. *IDS Bulletin*, **35**(3), pp. 15-21.
ICLEI, 2006: *Climates for City Protection (CCP) Campaign.* http://www.iclei.org/
IEA (International Energy Agencey), 2005: *Electricity Information 2005.* Organization for Economic Cooperation and Development, Paris, France.
Ikeme, 2003: Climate change adaptation deficiencies in developing countries: The case of sub- saharan Africa. *Global Change*, **8**(29-52)
IPCC (Intergovernmental Panel on Climate Change), 2002: *Climate Change and Biodiversity.* IPCC, Geneva, Switzerland.
IPCC, 2001a: *Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 397pp.
IPCC, 2001b: *Climate Change 2001 - Mitigation. Contribution of Working Group III to the Third Assessment Report of the IPCC.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 752pp.
IPCC, 2001c: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA, 1032pp.
IRM, AIRMIC, and ALARM, 2002: *A Risk Management Standard.* AIRMIC, IRM, ALARM, London, 17pp.
Jaffe, A.B., R.G. Newell, and R.N. Stavins, 2005: A tale of two market failures: Technology and environmental policy. *Ecological Economics*, **54**(2-3), pp. 164.
Jaffe, A.B., and R.N. Stavins, 1994: The energy-efficiency gap: What does it mean? *Energy Policy*, **22**(10), pp. 804-810.
Jahan, S., and A. Umana, 2003: The environment-poverty nexus. *Development Policy Journal*, **3**, pp. 53-70.
Kane, S., and J.F. Shogren, 2000: Linking adaptation and mitigation in climate change policy. *Climatic Change*, **45**(75-102)
Kasperson, J.X., and R.E. Kasperson, 2005: *The Social Contours of Risk.* Earthscan, London.
Keeney, R.L., and H. Raiffa, 1976: *Decisions with Multiple Objectives.* John Wiley and Sones, New York.
Klein, R., 2001: *Adaptation to climate change in German Official Development Assistance - An Inventory of Activities and Opportunties, with a Special Focus on Africa.*, Deutsche Gesellschaft für Technische Zusammenarbeit, Eschborn, Germany, 44pp.
Klein, R.J.T., E.L. Schipper, and S. Dessai, 2005: Integrating mitigation and adaptation into climate and development policy: three research questions. *Environmental Science and Policy*, **8**, pp. 579-588.
Koonjul, J., 2004: The special case of Small Island States for sustainable development. *Natural Resources Forum*, **28**, pp. 155-156.
Kulindwa, K., 2002: Economic reforms and the prospect for sustainable development in Tanzania. *Development Southern Africa*, **19**(3), pp. 389-404.

Lehtonen, M., 2004: The environmental-social interface of sustainable development: capabilities, social capital, institutions. *Ecological Economics*, **49**(2), pp. 199-214.
Lorenzoni, I., N.F. Pidgeon, and R.E. O'Connor, 2005: Dangerous climate change: the role for risk research. *Risk Analysis*, **25**(6), pp. 1387-1398.
Manne, A.S., and R.G. Richels, 1992: *Buying Greenhouse Insurance.* MIT Press, Cambridge, Mass.
Markandya, A., and K. Halsnaes, 2000: *Climate Change and its Linkages with development, equity and sustainability.* Intergovernmental Panel on Climate Change.
Martens, P., and J. Rotmans (eds.), 2002: *Transitions in a Globalising World*. Swets and Zeitlinger Publishers, Lisse.
Mastrandea, M.D., and S.H. Schneider, 2001: Integrated assessment of abrupt climate change. *Climate Policy*, **1**, pp. 433-449.
Mastrandea, M.D., and S.H. Schneider, 2004: Probabilistic integrated assessment of "dangerous" climate change. *Science*, pp. 571-575.
McDonald, S., S. Robinson, and K. Thierfelder, 2006: Impact of switching production to bioenergy crops: The switchgrass example. *Energy Economics*, **28**, pp. 243-265.
McLean, R.F., A. Tsyban, V. Burkett, J.O. Codignotto, D.L. Forbes, N. Mimura, R.J. Beamish, V. Ittekkot, L. Bijlsma, and I. Sanchez-Arevalo, 2001: Coastal zones and marine ecosystems. In: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Report of Working Group II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, pp. 343-379.
McMichael, A., A. Githeko, R. Akhtar, R. Carcavallo, D. Gubler, A. Haines, R. Kovats, P. Martens, J. Patz, and A. Sasaki, 2001: Human Health. In: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Report of Working Group II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, U.K., pp. 453-478.
MEA (Millennium Ecosystem Assessment), 2005: *Ecosystems and human well-being: Synthesis.* Island Press, Washington, D.C.
Metz, B., M. Berk, M. den Elzen, B. de Vries, and D. van Vuuren, 2002: Towards an equitable global climate regime: compatibility with Article 2 of the Climate Change Convention and the link with sustainable development. *Climate Policy*, **2**, pp. 211-230.
Ministry for Rural Affairs and the Environment Malta, 2004: *The First Communication of Malta to the UNFCCC.*
Misra, B.M., 2003: Advances in nuclear desalination. *Inernational Journal of Nuclear Desalination*, **1**, pp. 19-29.
Morita, T., J. Robinson, J. Adegulugbe, J. Alcamo, D. Herbert, E. La Rovere, N. Nakicenovic, H. Pitcher, P. Raskin, K. Riahi, A. Sankovski, V. Sokolov, B. de Vries, and D. Zhou, 2001: Greenhouse Gas Emission Mitigation Scenarios and Implications. In: *Climate Change 2001 - Mitigation. Report of Working Group III of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, pp. 115-166.
Moss, R., A. Brenkert, and E. Malone, 2001: *Vulnerability to climate change: A Quantitative Approach.* Pacific Northwest National Lab (PNNL-SA-33642).
Munasinghe, M., 1992: *Environmental Economics and Sustainable Development.* World Bank., Washington DC.
Munasinghe, M., and R. Swart (eds.), 2000: *Climate Change and its Linkages with Development, Equity and Sustainability*. Intergovernmental Panel on Climate Change, Geneva.
Munasinghe, M., and R. Swart, 2005: *Primer on Climate Change and Sustainable Development.* Cambridge University Press, Cambridge, 458pp.
Nagai, H., and C. Hepburn, 2005: How cost effective are carbon emission reductions under the Prototype Carbon Fund? In: *Environment and Change and Management*. Oxford University, Oxford, pp. 132.
Najam, A., A. Rahman, S. Huq, and Y. Sokona, 2003: Integrating sustainable development into the Fourth Assessment Report of the IPCC. *Climate Policy*, **3S1**, pp. S9-S17.

Nakicenovic, N., and R. Swart (eds.), 2000: *Special Report on Emissions Scenarios. Report of Intergovernmental Panel on Climate Change*. Cambridge University Press, London.
Nederveen, A., J. Konings, and J. Stoop, 2003: Globalization, international transport and the global environment: Technological innovation, policy making and the reduction of transport emissions. *Transportation Planning and Technology*, **26**(1), pp. 41-67.
Nicholls, R., and J.A. Lowe, 2004: Benefits of mitigation of climate change for coastal areas. *Global Environment Change*, **14**, pp. 229-244.
Nordhaus, W.D., 2001: Global warming economics. *Science*, **294**, pp. 1283 - 1284.
ODPM, 2004: *The planning response to climate change: Advice on better practice.* Office of the Deputy Prime Minister.
ODPM, 2005: *Planning Policy Statement I: Delivering Sustainable Development.* Office of the Deputy Prime Minister.
OECD, 2003: *Special Issue on Climate Change: Climate Change Policies: Recent development and long term issues*, 4 (2), OECD Publications, Paris.
Olsen, J.P., and J.G. March, 1989: *Rediscovering Institutions: The Organizational Basis of Politics.* The Free Press, New York.
Parry, M., N. Arnell, M. Hulme, R. Nicholls, and M. Livermore, 1998: Adapting to the inevitable. *Nature*, **395**(6704), pp. 741.
Payne, J.T., A.W. Wood, A.F. Hamlet, R.N. Palmer, and D.P. Lettenmaier, 2004: Mitigating the effects of climate change on the water resources of the Columbia River Basin. *Climatic Change*, **62**(1-3), pp. 233-256.
Peters, M., R. House, J. Lewandrowski, and H. McDowell, 2001: Economic impacts of carbon charges on U.S. agriculture. *Climatic Change*, **40**, pp. 445-473.
Pierson, P., 2004: *Politics in Time: History, Insitutions and Social Analysis.* Princeton University Press, Princeton, NJ.
Raiffa, H., 1968: *Decision Analysis.* Addison-Wesley, Reading, Massachucetts.
Raskin, P., G. Gallopin, and *et al*., 2002: *Bending the Curve: Toward Global Stability.* Stockholm Environment Institute, Global Scenario Group, Stockholm, 144pp.
Rip, A., and R. Kemp, 1998: Technolgical Change. In: *Human Choice and Climate Change*. Batelle Press, Columbus, Ohio
Robinson, J., 2004: Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, **48**, pp. 369-384.
Robinson, J., M. Bradley, P. Busby, D. Connor, A. Murray, B. Sampson, and W. Soper, 2006: Climate change and sustainable development: Realizing the opportunity. *Ambio*, **35**(1), pp. 2-8.
Robinson, J., M. Bradley, P. Busby, D. Connor, A. Murrey, and B. Sampson, 2003: Climate change and sustainable development: Realizing the opportunity at the world climate change conference Moscow., Sept 30 - Oct 4.
Robinson, J., and D. Herbert, 2001: Integrating climate change and sustainable development. *International Journal of Global Environmental Issues*, **1**(2), pp. 130-149.
Rogers, E.M., 2003: *Diffusion of Innovations.* Free Press, New York, 5th ed.
Rosenberg, N.J., and M.J. Scott, 1996: Implications of Policies to Prevent Climate Change for Future Food Security. In: *Climate Change and World Food Security*. Springer, Oxford, UK, pp. 551-589.
Ruth, M., 2005: Future socioeconomic and political challenges of global climate change. In: *From Resource Scarcity to Ecological Security: Exploring New Limits to Growth*. MIT Press, Cambridge, Mass.
Ruth, M., and A.-C. Lin, forthcoming: Regional energy demand and adaptations to climate change: Methodology and application to the state of Maryland, USA. *Energy Policy, in press.*
Sarkar, J., 1998: Technological diffusion: alternative theories and historical evidence. *Journal of Economic Survey*, **12**(2), pp. 131-176.
Schelling, T.C., 1995: Intergenerational discounting. *Energy Policy*, **23**(4/5), pp. 395-401.
Schneider, S.H., 2003: *Abrupt non-linear climate change, irreversibility, and surprise.* OECD, Paris.

Schneider, S.H., W. Easterling, and L. Mearns, 2000: Adaptation: Sensitivity to natural variability, agent assumptions and dynamic climate changes. *Climatic Change*, **45**(1), pp. 203-221.
Seck, M., N.A. Mamouda, and S.Wade, 2005: *Senegal adaptation and mitigation through produced environments: the case for agricultural intensification in Senegal*, in Vulnerability, Adaptation and Climate Disasters: A Conceptual Over view, (eds) Yamin, F., A. Rahman and S. Huq, IDS Bulletin 36 (4), pp 71-86.
Smil, V., 2000: Energy in the 20th century: resources, conversions, costs, uses and consequences. *Annual Review of Energy & the Environment*, **25**, pp. 21-51.
Smit, B., O. Pilifosova, I. Burton, B. Challenger, S. Huq, R. Klein, and G. Yohe, 2001: Adaptation to Climate Change in the Context of Sustainable Development and Equity. In: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Report of Working Group II of the Intergovernmental Panel on Climate Change*. Cambridge University Press., Cambridge, U.K., pp. 879-906.
Smith, J., and D. Tirpak (eds.), 1989: *Potential Impacts of Global Climate Change on the United States*. Environmental Protection Agency, Washington, D.C.
Southampton City Council, 2004: *Climate Change, Air Quality Strategy and Action Plan.*
Sperling, F. (ed.), 2003: *Poverty and Climate Change: Reducing the Vulnerability of the Poor through Adaptation*. AfDB, ADB, DFID, EC DG Development, BMZ, DGIS, OECD, UNDP, UNEP and the World Bank, Washington, DC, USA, xii+43pp.
Stainforth, D.A., T. Aina, C. Christensen, M. Collins, N. Faull, D.J. Frame, J.A. Kettleborough, S. Knight, A. Martin, J.M. Murphy, C. Piani, D. Sexton, L.A. Smith, R.A. Spicer, A.J. Thorpe, and M.R. Allen, 2005: Uncertainty in predictions of the climate response to rising levels of greenhouse gases. *Nature*, **433**(27), pp. 403-405.
Stern, P.C., and T. Dietz, 1994: The value basis of environmental concern. *Journal of Social Issues*, **50**(3), pp. 65-84.
Swart, R., J. Robinson, and S. Cohen, 2003: Climate change and sustainable development: expanding the options. *Climate Policy*, **3**(S1), pp. S19-S40.
Tol, R.S.J., 2003: Is the uncertainty about climate change too large for expected cost-benefit analysis? *Climatic Change*, **56**(3), pp. 265-289.
Tol, R.S.J., 2005a: Adaptation and mitigation: trade-offs in substance and methods. *Environmental Science and Policy*, **8**(6), pp. 572-578.
Tol, R.S.J., 2005b: The marginal damage cost of carbon dioxide emissions: An assessment of the uncertainties. *Energy Policy*, **33**(16), pp. 2064-2074.
Tol, R.S.J., 2005c: Emission abatement versus development as strategies to reduce vulnerability to climate change: An application of FUND. *Environment and Development Economics*, **10**, pp. 615-629.
Tol, R.S.J., forthcoming: The double trade-off between adaptation and mitigation for sea-level rise: An application of FUND. *Mitigation and Adaptation Strategies for Global Change*
Tol, R.S.J., and H. Dowlatabadi, 2001: Vector-borne diseases, climate change, and economic growth. *Integrated Assessment*, **2**, pp. 173 - 181.
Tol, R.S.J., and G. Yohe, 2006: Of dangerous climate change and dangerous emission reduction. In: *Avoiding Dangerous Climate Change*. Cambridge University Press, Cambridge, U.K., pp. 291-298.
Tompkins, E., and W.N. Adger, 2003: Defining a response capacity for climate change. *Environmental Science and Policy*, **8**(6), pp. 562-571.
Toth, F., 2003: State of the art and future challenges for integrated environmental assessment. *Integrated Assessment*, **4**, pp. 250-264.
Toth, F., M. Mwandosya, C. Carraro, J. Christensen, J. Edmonds, B. Flannery, G.-G. Carlos, H. Lee, K.M. Meyer-Abich, E. Nikitina, A. Rahman, R. Richels, Y. Ruqiu, A. Villavicencio, Y. Wake, and J. Weyant, 2001: Decision-making frameworks. In: *Climate Change 2001: Mitigation, Report of Working Group III, Intergovernmental Panel on Climate Change*. Cambridge University Press,

Cambridge
Toth, F.L., T. Bruckner, H.-M. Füssel, M. Leimbach, and G. Petschel-Held, 2003a: Integrated assessment of long-term climate policies: Part 1 - Model presentation. *Climatic Change*, **56**(1-2), pp. 37-56.
Toth, F.L., T. Bruckner, H.-M. Füssel, M. Leimbach, and G. Petschel-Held, 2003b: Integrated assessment of long-term climate policies: Part 2 - Model results and uncertainty analysis. *Climatic Change*, **56**(1-2), pp. 57-72.
Toth, F.L., T. Bruckner, H.-M. Füssel, M. Leimbach, G. Petschel-Held, and H.-J. Schellnhuber, 2002: Exploring options for global climate policy in an inverse integrated assessment framework. *Environment*, **44**(5), pp. 23-34.
UK FRP (United Kingdom Forestry Research Programme), 2005: *From the mountain to the tap: How land use and water management can work together for the rural poor.* UK FRP, London, U.K.
United Nations, 2000: *United Nations Millennium Declaration. Resolution adopted by the General Assembly, 55th Session, 18 September. A/RES/55/22.* United Nations.
Unruh, G., and J. Carrillo-Hermosilla, 2006: Globalizing carbon lock-in. *Energy Policy*, **34**, pp. 1185-1197.
Van Asselt, H., J. Gupta, and F. Biermann, 2005: Advancing the climate agenda: Exploiting material and insitutional linkages to develop a menu of policy options. *Review of European Community and International Environmental Law*, **14**(3), pp. 255-263.
Vanrheenen, N.T., A.W. Wood, R.N. Palmer, and D.P. Lettenmaier, 2004: Potential implications of PCM climate change scenarios for Sacramento-San Joaquin River Basin hydrology and water resources. *Climatic Change*, **62**(1-3), pp. 257-281.
Venema, D. H., E.J.Schiller, K.Adammowski and J.M. Thizy, 1997: *A water resource planning response to climate change in Senegal River basin,* J. Environmental Management**, 49**, pp125-155.
Vulnerability Net, 2006. See the Document Hotel at: www.VulnerabilityNet.org. Last accessed 17 May 2006.
Warren, R., 2006: Impacts of global climate change at different annual mean global temperature rises. In: *Avoiding Dangerous Climate Change*. Cambridge University Press, Cambridge, U.K., pp. 93-131.
Watson, R.T. (ed.), 2002: *Climate Change 2001: Synthesis Report, Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, London.
Weyant, J., 2004: Special issue - EMF19 alternative technology strategies for climate change policy. *Energy Economics*, **26**(4), pp. 501-515.
Wilbanks, T., 2003: Integrating climate change and sustainable development in a place-based context. *Climate Policy*, **3**(S1), pp. S147-S154.
Wilbanks, T., and R. Kates, 2003: Making the global local: Responding to climate change concerns from the bottom up. *Environment*, **45**(3), pp. 12-23.
Winkler, H., K. Baumert, O. Blanchard, S. Burch, and J. Robinson, Forthcoming: What factors influence mitigative capacity? *Energy Policy*
Woolcock, N., and D. Narayan, 2000: Social capital: implications for development theory, research, and policy. *World Bank Research Observer*, **15**, pp. 225-249.
World Bank, no date: *Community Development Carbon Fund*.
Yohe, G., 2001: Mitigative capacity: the mirror image of adaptive capacity on the emissions side. *Climatic Change*, **49**(3), pp. 247-262.
Yohe, G., and R.S.J. Tol, 2002: Indicators for social and economic coping capacity: Moving toward a working definition of adaptive capacity. *Global Environmental Change*, **12**, pp. 25-40.
Young, O., 2002: *The Institutional Dimensions of Environmental Change - Fit, Interplay, and Scale.* MIT Press, Cambridge, Mass.