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Climate-Resilient Pathways: Adaptation, Mitigation, and Sustainable Development

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Executive Summary

Climate change calls for new approaches to sustainable development that take into account complex interactions between climate and social and ecological systems. Climate-resilient pathways are development trajectories that combine adaptation and mitigation to realize the goal of sustainable development. They can be seen as iterative, continually evolving processes for managing change within complex systems.

This chapter integrates a variety of complex concepts in assessing climate-resilient pathways. It takes sustainable development as the ultimate goal, and considers mitigation as a way to keep climate change moderate rather than extreme. Adaptation is considered a response strategy to anticipate and cope with impacts that cannot be (or are not) avoided under different scenarios of climate change. In most cases, sustainable development will also involve capacities for implementing and sustaining appropriate risk management. Responses may differ from situation to situation, calling for a multiscale perspective that takes the socioeconomic, cultural, biophysical, and institutional context into account. Nonetheless, most situations share at least one fundamental characteristic: threats to sustainable development are greater if climate change is substantial rather than moderate. Similarly, opportunities for sustainable development are greater if climate change is moderate rather than substantial.

Although findings from this chapter are based on a high level of consensus in source materials and in the expert communities, the amount of supporting evidence is relatively limited because so many aspects of sustainable development and climate change mitigation and adaptation have yet to be experienced and studied empirically. The task of this chapter is to suggest options to be considered for decision making, both now and in the future, as elements of the evolving processes for a variety of locations and scales. This chapter's findings are as follows.

Climate change poses a moderate threat to current sustainable development and a severe threat to future sustainable development (*high confidence*; *medium evidence*, *high agreement*). Some climate-related impacts on development are already being observed (e.g., changes in agriculture, increases in coastal vulnerability). Added to other stresses such as poverty, inequality, or diseases, the effects of climate change will make sustainable development objectives such as food and livelihood security, poverty reduction, health, and access to clean water more difficult to achieve for many locations, systems, and affected populations. {20.2.1}

Climate-resilient pathways include strategies, choices, and actions that reduce climate change and its impacts. They also include actions to ensure that effective risk management and adaptation can be implemented and sustained (*high confidence*; *medium evidence*, *high agreement*). Adaptation and mitigation have the potential to both contribute to and impede sustainable development, and sustainable development strategies and choices have the potential to both contribute to and impede climate change responses. Adaptation and mitigation are needed, working together to reduce risks of disruptions from climate change. These actions, however, may introduce trade-offs between adaptation and mitigation, and between economic goals and environmental goals. In some cases, for example, adaptation may increase greenhouse gas emissions (e.g., increased fossil-based air conditioning in response to higher temperatures) and in some cases mitigation may impede adaptation (e.g., reduced energy availability in countries with growing populations). In many cases, strategies for climate change responses and strategies for sustainable development are highly interactive. {20.3-4}

The integration of adaptation and mitigation responses can in some cases generate mutual benefits, as well as introduce co-benefits with development policies (*high confidence*; *medium evidence*, *medium agreement*). In many cases, reducing the risk of climate change can enhance capacities for management of other risks. Opportunities to take advantage of positive synergies may decrease with time, particularly if the limits to climate change adaptation are exceeded. {20.2.1, 20.3.2-3, 20.5.1}

Prospects for climate-resilient pathways are related fundamentally to what the world accomplishes with climate change mitigation, but both mitigation and adaptation are essential for climate change risk management at all scales (*high confidence*; *medium evidence*, *high agreement*). As the magnitude of climate change increases and the consequences become increasingly significant to many areas, systems, and populations, the challenges to sustainable development increase. Beyond some magnitudes and rates of climate change, the impacts on most systems would be great enough that sustainable development may no longer be possible for many systems and locations. At the local scale, governments, businesses, communities, and individuals in many developing regions have limited capacities to mitigate climate

change because they contribute very little to global emissions. They may also have relatively limited capacities to adapt for reasons of income, education, health, security, political power, or access to technology. At all scales, however, mitigation and adaptation actions are fundamental for effective implementation of climate risk management and reduction. {20.2.2, 20.3, 20.6.1}

To promote sustainable development within the context of climate change, climate-resilient pathways may involve significant transformations (*high confidence*; *medium evidence*, *high agreement*). Transformations in economic, social, technological, and political decisions and actions can enable climate-resilient pathways. Although transformations may be reactive, forced, or induced by random factors, they may also be deliberately created through social and political processes. Whether in relation to mitigation, adaptation, or sustainable development, it is possible to identify enabling conditions that support transformations. Nonetheless there are legitimate concerns about the equity and ethical dimensions of transformation. {20.5}

Strategies and actions can be pursued now that will move toward climate-resilient pathways while at the same time helping to improve livelihoods, social and economic well-being, and responsible environmental management (*high confidence*; *medium evidence*, *high agreement*). Transformations to sustainability benefit from iterative learning, deliberative processes, and innovation. {20.4}

Delayed action in the present may reduce options for climate-resilient pathways in the future (*high confidence*; *medium evidence*, *high agreement*). In some parts of the world, current failures to address effects of emerging climate stressors are already eroding the basis for sustainable development and offsetting previous gains. Opportunities to design and implement solutions that promote climate-resilient pathways exist now, and they can capture development co-benefits of improving livelihoods and social and economic well-being. Current actions will emphasize climate risk management strategies informed by growing evidence, knowledge, and experience. {20.6.2}

More research about the relationship between mitigation, adaptation, and sustainable development is needed, as well as research on the relationship between incremental changes and more significant transformations for sustainable development (*high confidence*; *robust evidence*, *high agreement*). Priorities for research include improving understandings of benefits, costs, synergies, trade-offs, and limitations of major mitigation and adaptation options, along with implications for equitable development to facilitate decision making about climate-resilient pathways (*high confidence*; *robust evidence*, *high agreement*).

20.1. Introduction

Following summaries of *what we know* about climate change impacts, vulnerabilities, and prospects for adaptation (Chapter 18) and reasons for concern (Chapter 19), this chapter summarizes what is currently known about options regarding *what to do* in responding to these risks and concerns.

In terms of "what to do" to address climate change and threats to development now and in the future, the chapter identifies and discusses climate-resilient pathways. Climate-resilient pathways are defined in this chapter as development trajectories that combine adaptation and mitigation with effective institutions to realize the goal of sustainable development. They are seen as iterative, continually evolving processes for managing change within complex socio-ecological systems; taking necessary steps to reduce vulnerabilities to climate change impacts in the context of development needs and resources, building capacity to increase the options available for vulnerability reduction and coping with unexpected threats; monitoring the effectiveness of vulnerability reduction efforts; and revising risk reduction responses on the basis of continuous learning. As such, climate-resilient pathways include two main categories of responses:

- Actions to reduce human-induced climate change and its impacts, including both mitigation and adaptation toward achieving sustainable development
- Actions to ensure that effective institutions, strategies, and choices for risk management will be identified, implemented, and sustained as an integrated part of achieving sustainable development.

In many cases, each of the two categories of responses has the potential to benefit the other as well, offering potentials for win-win kinds of integration, although mechanisms and institutions are needed to address cases where the two elements have negative effects on each other and to ensure that positive synergies are realized. Because climate change challenges are significant for many areas, systems, and populations, climate-resilient pathways will generally require transformations—beyond incremental approaches—in order to ensure sustainable development (see Sections 20.2.3.1, 20.6.2; for related language employed by the UNFCCC, see Box 20-1).

Incremental responses to climate change address immediate and anticipated threats based on current practices, management approaches, or technical strategies. These may involve developing energy-efficient vehicles to mitigate climate change, or building higher dykes to adapt to sea level rise. Incremental responses are often referred to as business-as-usual approaches, as they do not challenge or disrupt existing systems (Kates et al., 2012). Transformative responses, in contrast, involve innovations that contribute to systemic changes by challenging some of the assumptions that underlie business-as-usual approaches (O'Brien, 2012). Transformational adaptations, for example, change the nature, composition, and/or location of threatened systems (Smit and Wandel, 2006; Stringer et al., 2009; National Research Council, 2010a; Pelling, 2010; IPCC, 2012). Importantly, transformations of the systems, structures, relations, and behaviors that contribute to climate change and social vulnerability may also be necessary to reduce risks to sustainable development, as discussed in Section 20.5.2 (see also WGIII AR5 Chapter 6 on Assessing Transformation Pathways).

Frequently Asked Questions

FAQ 20.1 | What is a climate-resilient pathway for development?

A climate-resilient pathway for development is a continuing process for managing changes in the climate and other driving forces affecting development, combining flexibility, innovativeness, and participative problem solving with effectiveness in mitigating and adapting to climate change. If effects of climate change are relatively severe, this process is likely to require considerations of transformational changes in threatened systems if development is to be sustained without major disruptions.

Conceptual understandings of sustainable development have developed considerably, particularly over the past 2 decades, as the short- and long-term implications of climate change and extreme events have become better understood, although empirical evidence of progress with sustainable development is often elusive. The discussion of sustainable development in the IPCC process has evolved since the First Assessment Report (FAR), which focused on the technology and cost-effectiveness of mitigation activities, and the Second Assessment Report (SAR), which included issues related to equity and to environmental and social considerations. The Third Assessment Report (TAR) further broadened the treatment of sustainable development by addressing issues related to global sustainability, and the Fourth Assessment (AR4) included chapters on sustainable development in both Working Group II and III reports, with a focus on both climate-first and development-first literatures.

This chapter recognizes climate change as a threat to sustainable development. The chapter emphasizes that, as a result, transformational changes are very likely to be required for climate-resilient pathways—both transformational adaptations and transformations of social processes that make such transformational adaptations feasible. The chapter integrates a variety of complex issues in assessing climate-resilient pathways in a variety of regions at a variety of scales: sustainable development as the ultimate aim, mitigation as the way to keep climate change impacts moderate rather than extreme, adaptation as a response strategy the way to keep climate change impacts moderate rather than extreme or to cope with impacts that cannot be (or are not) avoided, and development pathways as contexts that shape choices and actions. It stresses needs and opportunities to make progress toward climate-resilient pathways now, rather than postponing responses to an indefinite future.

The chapter is organized in six parts: climate change as a threat to sustainable development, by assessing links between sustainable development and climate change as well as defining climate-resilient pathways (Section 20.2); contributions to resilience through climate change responses (Section 20.3); contributions to resilience through

Box 20-1 | Goals for Climate-Resilient Pathways

Climate-resilient pathways are development trajectories of combined mitigation and adaptation to realize the goal of sustainable development that help avoid "dangerous anthropogenic interference with the climate system" as specified in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC).

Article 2 of the UNFCCC outlines its ultimate objective as the "*stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system* … in order 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." Article 3.4 of the Convention recognizes that "*Parties have a right to and should promote sustainable development.*" A number of recent decisions by the Conference of the Parties (COP) to the UNFCCC has attempted to recognize the scientific view that the increase in global temperature should be below 2°C and encourage long-term cooperative action to combat climate change. The Decisions agreed in Cancun at COP-16 recognize "… *deep cuts in global greenhouse gas emissions are required according to science*, and as documented in the Fourth Assessment Report of the IPCC, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2°C above preindustrial levels … consistent with science … [and] also recognizes the need to consider … strengthening the long-term global goal on the basis of the best available scientific knowledge." The preamble of the Cancun Decisions highlights the central importance of the link between climate change and employment and "*Realizes that addressing climate change requires a paradigm shift towards building a low-carbon society that offers substantial opportunities and ensures continued high growth and sustainable development, based on innovative technologies and more sustainable production and consumption and lifestyles, while ensuring a just transition of the workforce that creates decent work and quality jobs*" (UNFCCC, 2011, Decision 1/CP.16). The 2011 COP, in a decision known as the Durban Platform, increases the strength of the language in the Decision 1/CP.17 to conclude, "… *climate change represents an urgent and potentially irreversible threat to human societies and the planet* and thus requires to be urgently addressed … with a view to accelerating the reduction of global greenhouse gas emissions…." This decision was followed by the decisions adopted in Doha at the 18th Conference of the Parties that noted with grave concern the significant gap between the aggregate effect of Parties' mitigation pledges in terms of global annual emissions of greenhouse gases by 2020 and aggregate emission pathways consistent with having a likely chance of holding the increase in global average temperature below 2°C or 1.5°C above preindustrial levels. As such, the current UNFCCC negotiations have identified +2°C or 1.5°C as the desirable target upper limit,implicitly equating this with "dangerous" in Article 2.

sustainable development strategies and choices (Section 20.4); determinants of resilience in the face of serious threats (Section 20.5); challenges in moving toward climate-resilient pathways (Section 20.6); and priority gaps in knowledge (Section 20.7).

Several of the terms that are central to this chapter have been defined earlier in the WGII contribution to the Fifth Assessment Report, including climate, adaptation, and mitigation. In addition, by "resilient" we mean a system's ability to anticipate, reduce, accommodate, and recover from disruptions in a timely, efficient, and fair manner (IPCC, 2012). For literatures on "sustainable development," see Section 20.2. A summary definition is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (see Glossary). It achieves continuing improvements in human well-being and ensures a sustainable relationship with a physical environment that is already under stress, reconciling trade-offs among economic, environmental, and other social goals through institutional approaches that are equitable and participative in order themselves to be sustainable.

Frequently Asked Questions

FAQ 20.2 | What do you mean by "transformational changes"?

Transformational change is a fundamental change in a system, its nature, and/or its location that can occur in human institutions, technological and biological systems, and elsewhere. It most often happens in responding to significantly disruptive events or concerns about them. For climate-resilient pathways for development, transformations in social processes may be required to get voluntary social agreement to undertake transformational adaptations that avoid serious disruptions of sustainable development.

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20.2. Climate Change as a Threat to Sustainable Development

Climate-resilient pathways bring together (1) sustainable development as the larger context for societies, regions, nations, and the global community with (2) climate change effects as threats to (and possibly opportunities for) sustainable development and (3) responses to reduce any effects that would undermine future development and even offset already achieved gains. Resilience is defined in this report as the ability of a social, ecological, or socio-ecological system and its components to anticipate, reduce, accommodate, or recover from the effects of a hazardous event or trend in a timely and efficient manner (see Glossary). Climate resilience refers to the outcomes of evolutionary processes of managing change in order to reduce disruptions and enhance opportunities. Considering alternative climate-resilient pathways cannot be separated from levels of climate change. Overall, most climate change scientists, decision makers, and stakeholders agree that (1) there is a level of climate change that is low enough that climate resilience for most systems could be achieved without enormous efforts and widespread transformational adaptation; (2) there is a level of climate change that is high enough that climate resilience cannot be expected to cope with severe impacts on most systems (e.g., Rockstrom et al., 2009); and (3) between those two levels the challenges to climate resilience grow as the level of climate change rises. Scientists do not, however, agree on what magnitude of climate change (e.g., average global warming) defines each of the two levels. Some experts support the view (Box 20-1 and Section 20.3.1) that any level above 2°C would mean impacts that are incompatible with sustainable development (Metz et al., 2002). The Summary for Policymakers of the WGII AR4 indicated that there is an approximate threshold between 2.5°C and 3°C of warming, above which impact concerns are severe but below which concerns are less severe (IPCC, 2007b, Figure SPM.2; see also Smith et al., 2009). Other scientists are unconvinced that system sensitivities to climate parameters such as temperature increase are understood well enough to support any specific warming threshold (e.g., National Research Council, 2010c), and some scientists and policymakers are unconvinced that adaptive management and adaptive response capacities are well enough understood to support determinations of limits to adaptation and resilience (Chapter 16). Most experts in all three groups, however, agree that prospects for climate-resilient development pathways are related fundamentally to what the world accomplishes with climate change mitigation (e.g., New et al., 2012).

20.2.1. Links between Sustainable Development and Climate Change

20.2.1.1. Objectives of Sustainable Development

Different actors have used the concept of sustainable development to pursue a variety of objectives in policy and practice worldwide, with the common denominator of delivering improved human well-being while sustaining environmental services (Sen, 1999; Morgan and Farsides, 2009; Von Bernard and Gorbaran, 2010). "Sustainable development" is a concept rooted in concerns about balance in the relationships between society and nature (e.g., Brown, 1981). The Brundtland Report (WCED, 1987, p. 43) defines the idea as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." It contains within it two key concepts of "needs": in particular the essential needs of the world's poorest, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs (Rao, 2000). It stresses that equitable economic development is key to addressing environmental problems both in developing and developed regions in ways that are sustainable for the long term (Halsnaes et al., 2008; Lafferty and Meadowcroft, 2010).

Historically, policy and science have subsequently influenced the development of the concept. Concerns about declining environmental quality, and increasing population growth, coupled with increasing rates of consumption (energy, natural resources, input-intensive living standards), motivated changes in some countries, related for example to:

- Water and air quality standards
- Management of hazardous materials
- Changes in regulation (although some literature says that current institutional controls and linkages are counterproductive (Barker, 2008; O'Hara, 2009; Scrieciu et al., 2013))
- Agricultural and industrial practices
- Water and solid waste management
- A movement toward greater efficiency in resource use including recycling
- An emphasis on energy efficiency, progressing toward renewable energy as an alternative to non-renewable fossil fuel resources (Frey and Linke, 2002).

In this context, global discourse and practice have helped to establish principles and aspirational plans. Examples include Agenda 21, which is a comprehensive plan of action adopted at the 1992 Earth Summit by more than 178 governments (Sitarz, 1994) and the 2012 "Rio+20" conference, which issued a statement urging countries to renew their commitment to sustainable development. Improved understandings of the short- and long-term implications of climate change and extreme events (IPCC FAR, SAR, TAR, AR4, *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX)) have influenced conceptualizations of sustainable development and related objectives such as poverty reduction, health, livelihood and food security, and other aspects of human welfare related to the idea of "climate-resilient development." These discussions occurred against an emerging understanding of "rights to development" (e.g., UNFCCC Article 2), juxtaposed with the lack of consensus about justifiable patterns of consumption and a recognition that development processes have altered global environmental systems, including climates (Crutzen and Stoermer, 2000; IPCC, 2007a, 2012; Oliver-Smith et al., 2012). However, in practice some national authorities interpret sustainable development as pursuing current economic development (Beg et al., 2002; Swart et al., 2003; Arndt et al., 2012; Yohe, 2012), as many countries aspire to carbon-intensive development models akin to the systems in place in most industrialized countries—from food production, trade, and transport to household consumption (Grist, 2008; Brown, 2011; Sanwal, 2012).

In contrast, to many observers, carbon-intensive development models in industrialized and developing countries appear broadly inconsistent with objectives such as poverty reduction, improving human health, and securing food and livelihoods associated with the idea of sustainable development (Ehrenfeld, 2008; Grist, 2008; Marston, 2012; see also Victor and Rosenbluth, 2007; Victor, 2008) and with efforts to define and establish "safe operating spaces" for humanity (Röckstrom et al., 2009; Preston et al., 2013). While diverse interpretations of the concept are used, the literature suggests that many indicators of human welfare are already being compromised to some degree and at different scales by climate-related stressors (see Section 20.2.1.2).

One way that sustainable development pathways can contribute to climate resilience is by pursuing consumption patterns that ensure social and economic development while reducing use of natural resources and maintaining ecosystem services. It is possible that the desired objectives of consumption might be met in ways that require fewer resources and produce fewer emissions (Kates, 2000b; see also Leiserowitz et al., 2005). Ideas about equity and values play a role in sustainable development and how policy makers perceive trade-offs in aims to improve human well-being. In many cases, growth in consumption that raises human well-being (such as food and health services), especially among populations with incomes rising from low levels, is a catalyst for economic and social development (Clark et al., 2008; Deaton, 2008). In contrast, for populations already at high consumption levels, increasing material consumption does not necessarily translate into higher well-being (Easterlin, 1974, 2001; Adger, 2010; see also WGIII AR5 Chapter 4). This observation is reflected in research on subjective human happiness, satisfaction, and material comfort (Huesemann, 2006; Dolan and White, 2007; Fleurbaey, 2009; Cafaro, 2010; DeLeire and Kalil, 2010).

Box 20-2 | Key Reasons for Concern about Climate Change Effects on Sustainable Development

Chapter 19 identifies a number of "Key Risks, Key Vulnerabilities, and Reasons for Concern" (see especially Section 19.6.3 and Table 19-4). Emergent risks from climate change related to sustainable development include losses of ecosystem services, challenges to land and water management, effects on human health, particular risks of severe harm and loss in certain vulnerable areas, increasing prices of food commodities on the global market, consequences for migration flows at particular times and places, increasing risks of flooding, risks of food insecurity, systemic risks to infrastructures from extreme events, loss of biodiversity, and risks for rural livelihoods. These risks differ according to the magnitude of climate change and both regional and socioeconomic differences in vulnerability. Some unique and threatened systems are at risk at current temperatures, with risks increasing at even relatively small increases in global mean temperature. Risks grow if the magnitude of warming increases.

20.2.1.2. Risks and Threats Posed by Climate Change, Interacting with Other Factors and Driving Forces

As the implications of climate change and their extent become better understood (Chapter 18) and as particular reasons for concern have begun to come into focus (Chapter 19), climate change has been increasingly seen as an issue for sustainable development—with the potential either to aid or impede its successful implementation (e.g., Halsnaes et al., 2008; Munasinghe, 2010).

The links between sustainable development and climate adaptation and mitigation are cross-cutting and complex. First, the impacts of climate change, and ill-designed responses to these impacts, may derail current sustainable development policy and potentially offset already achieved gains. These impacts are expected to affect numerous sectors such as agriculture, forestry, and energy; threaten coastal zones and other vulnerable areas; and pose critical challenges to governance and political systems (World Bank, 2010, pp. 39-69; Adger et al., 2011; IPCC, 2012; see also Box 20-2 and Chapters 18, 19). Examples include poverty and livelihoods (Chapter 13), food security (Chapter 7), human security (Chapter 12), rural and urban areas (Chapters 8, 9), and economic sectors (Chapters 10, 17). For instance, effects of climate change on key ecological resources and systems can jeopardize sustainable development in systems closely dependent on natural capital. Moreover, although impacts will affect both developed and developing regions, the latter are considered especially problematic owing to lower adaptive capacity (World Bank, 2010, Chapter 13; Lemos et al., 2013). Second, mitigation has the potential to keep these threats at a moderate rather than extreme level, and adaptation will enhance the ability of different systems to cope with the remaining impacts, therefore modulating negative effects on sustainable development (IPCC, 2007a).

Third, many of the conditions that define vulnerability to climate impacts and the ability to mitigate and adapt to them are firmly rooted in development processes (e.g., structural deficits and available assets and entitlements) (Brooks et al., 2005; Lemos et al., 2013; see also Section 15.2.1). Indeed, climate change will act as a threat multiplier and will create new poor in low-income countries and middle- to high-income countries (Chapter 13). Fourth, sustainable development intersects with many of the drivers of climate change, especially regarding energy production and consumption and the ability to mitigate emissions (IPCC, 2011; see also Chapter 9). Fifth, because several of the desirable characteristics of climate responses and sustainable development may overlap (e.g., implementation of no-regrets options, equitable distribution of resources, increased adaptive capacity and livelihood capitals, functioning ecosystems and maintained biodiversity), systems that prioritize sustainable development may be better at designing and implementing successful mitigation and adaptation (Forsyth, 2007; Brown, 2011).

Finally, climate mitigation and adaptation, if planned and integrated well, have the potential to create opportunities to foster sustainable development (see Section 20.3.3). Under the threat of climate change, sustainable development depends on changes in social awareness and values that lead to innovative actions and practices, including increased attention to both disaster risk management and climate change adaptation in anticipation of (and in response to) changes in climate extremes (IPCC, 2012). Understanding how to enhance positive feedbacks between mitigation, adaptation, and sustainable development (e.g., win-win and triple-win interventions) while minimizing potential trade-offs between them (see Section 20.3.3) is an essential part of planning for and pursuing climate-resilient pathways. In the following paragraphs, we discuss these links in light of empirical research and specific examples (Box 20-2; also see discussions of Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) in Chapter 1). While some of the links described above have been contemplated in the scholarly literature, there remain considerable gaps in our knowledge base to inform climate-resilient pathways.

Frequently Asked Questions

FAQ 20.3 | Why are climate-resilient pathways needed for sustainable development?

Sustainable development requires managing many threats and risks, including climate change. Because climate change is a growing threat to development, sustainability will be more difficult to achieve for many locations, systems, and populations unless development pathways are pursued that are resilient to effects of climate change.

The relationship between climatic change and development policy has often been theorized as essentially twofold. On the one hand, climate change will affect development policy as needs to respond to negative, and perhaps positive, impacts arise (Burton et al., 2002; Halsnaes and Verhagen, 2007; IPCC, 2007a; Schipper, 2007). On the other hand, development policy critically shapes carbon emission paths, the ability to develop sustainable adaptation and mitigation options, and to build overall adaptive capacity (Bizikova et al., 2007; Metz and Kok, 2008; Garg et al., 2009; Lemos et al., 2013). Because of the recognized relationship between development and climate change drivers and responses, some authors have called for a "political economy of climate change" that takes into consideration ideas, power, and resources at different scales from the local to the global (e.g., Tanner and Allouche, 2011).

Enhancing resilience to respond to effects of climate change includes adopting good development practices that are consonant with building sustainable livelihoods and, in some cases, challenging current models of development (Boyd et al., 2008; McSweeny and Coomes, 2011). Moreover, promoting development pathways that are both equitable and sustainable is also a key to addressing climate change (Wilbanks, 2003; Nelson et al., 2007). In this sense, integrating sustainable development and overall climate change policy can be all the more relevant if "cross-linkages between poverty, the use of natural capital and environmental degradation" are recognized (Veeman and Politylo, 2003, p. 317; see also Matthew and Hammill, 2009). Especially in less developed regions, the relationship between vulnerability to climate impacts and development is often very close and mutually dependent, as such realities as low per capita income and inequitable distribution of resources; lack of education, health care, and safety; and weak institutions and unequal power relations fundamentally shape sensitivity, exposure, and adaptive capacity to climate impact (Kates, 2000a; Adger et al., 2003; Garg et al., 2009; McSweeny and Coomes, 2011; Lemos et al., 2013). In these regions, reducing risks that affect resource-dependent communities is increasingly viewed as a necessary but insufficient way to tackle the myriad problems associated with climate change impacts (Jerneck and Olsson, 2008). Building the capacity of individuals, communities, and governance systems to adapt to climate impacts is both a function of dealing with developmental deficits (e.g., poverty alleviation, reducing risks related to famine and food insecurity, enabling/implementing public health and mass education and literacy programs) and of improving risk management (e.g., alert systems, disaster relief, crop insurance, seasonal climate forecasts, risk insurance) (Mirza, 2003; Schipper and Pelling, 2006; IPCC, 2012; Warner et al., 2012a; see also Chapters 12, 13). Hence, it is important to understand not only the relative importance of different kinds of interventions (climate and non-climate) in building adaptive capacity but also the potential positive and negative synergies between them (Lemos et al., 2013).

While research increasingly highlights the intersection between vulnerability, adaptive capacity, and developmental structural deficits (see Chapter 13 for a detailed discussion), there is also growing recognition that the intractability of many of these problems may inhibit the development of climate-resilient pathways. For example, in northeast Brazil, the fact that local traditional politics relied on patron-client relationships with drought-affected households to maintain power suggests that there was little incentive for policies that dramatically decreased their level of vulnerability (Tompkins et al., 2008). Omolo (2010) argues that in northwestern Kenya, in pastoralist societies of Turkana, in spite of increasing numbers of women-headed households, participation of women in key decisions such as investment, resource allocation, and planning on where to move or settle in the aftermath of drought and floods is still quite low. A serious concern is that our inability to readily address these kinds of structural problems may limit options for future generations of marginalized social groups to be active agents of a climate-resilient future. In this sense, it is critical to understand how existing path-dependent trajectories (e.g., socio-technical, behavioral, institutional) that form the contextual basis for climate change action at different scales (Burch, 2010) may inhibit (or help) the realization of future climate-resilient pathways.

A number of studies recognize that not every possible response to climate change is consistent with sustainable development, as some strategies and actions may have negative impacts on the well-being of others and of future generations (Gardiner et al., 2010; Eriksen et al., 2011; see also Section 19.3.2.5). For example, some mitigation interventions such as the subsidization of the ethanol industry in the USA might compromise long-term resilience through both undesirable ecological effects (e.g., loss of crop diversity, soil erosion, and aquifer depletion) and social effects (e.g., reduction of flexibility for alternative fuel development, potential for food insecurity; Adger et al., 2011). Likewise, in central Vietnam some responses to climate change impact, such as building dams to prevent flooding and saltwater intrusion and to generate power, threaten the livelihood of poor communities. First, the relocation of communities and the inundation of forestland to build dams limit households' access to land and forest products. Second, a government focus on irrigated rice agriculture can reduce poor households' ability to diversify their income portfolio, decreasing their long-term adaptive capacity (Beckman, 2011). Indeed, the consequences of responses to climate change, whether related to mitigation or adaptation, can negatively influence future vulnerability, unless there is awareness of and response to these interactions (Eriksen et al., 2011). Here, the role of values in responding to climate change becomes important from a variety of perspectives, including intergenerational, particularly when those currently in positions of power and authority assume that their prioritized values will be shared by future generations (O'Brien, 2009; Eriksen et al., 2011). Acknowledging the importance of intergenerational equity, it has been argued that participatory processes and "deliberative democracy" can include the concerns, values, and perceptions of a wide range of stakeholders, raising some of the ethical impacts attached to climate-related risks (Backstrand, 2003; see also Deere-Birebeck, 2009). Such an approach could have a bearing on the way risks are assessed and addressed at the science-policy interface, with significant implications for sustainable development. For example, research by Wolf et al. (2009) on climate change responses in western Canada shows that individual quests to minimize their environmental impact and sense of responsibility (normatively defined as ecological citizenship) play an important role in the identification and implementation of sustainable responses to water scarcity. In contrast, inequitable distribution of power among those affected by climate impact can suppress innovative decisions about the future by limiting participation in designing solutions. In light of the complex interactions among climate change responses and sustainable development, there is a need for more holistic responses that place human well-being and security at the forefront, while building on existing strengths and capacities (Tompkins and Adger, 2004; O'Brien et al., 2010). This entails integrating multiple objectives and policy goals in order to promote responses to climate change that contribute to resilience and that are sustainable as social and policy conditions change (Meadowcroft, 2000; Tompkins and Adger, 2004; Pintér et al., 2011).

A reality in many countries may be that development in its many forms (economic, human, and sustainable) can enhance the capacity to adapt (Lemos et al., 2013), while at the same time adding to greenhouse gas (GHG) emissions. Yet, the World Development Report 2010 suggests that climate change responses have the potential to contribute to sustainable development as, for example, in the case of financial assistance with transition to low-carbon growth paths (World Bank, 2010) or in the case of mitigation policies that could increase income and/or enhance the quality of growth in vulnerable groups such as Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+). And while vulnerable sectors such as agriculture give us particular reasons for concern (see Box 20-2), they may offer opportunities in some instances to reduce climate-related risks and threats by integrating both adaptation and mitigation strategies as a lever for reducing poverty and promoting climate-resilient pathways. Particularly necessary is addressing institutional and social capacities for responding to both climate change impacts and mitigation responses. For example, Chhatre and Agrawal (2009) show that climate change mitigation can benefit livelihoods if ownership of forest commons is transferred to local communities.

Some interventions related to climate change responses aim to combine goals of sustainable development, climate change adaptation, and climate change mitigation into "win-win" or "triple-win" approaches that highlight overlaps between these goals. Examples include mechanisms such as the Clean Development Mechanism (CDM) and Joint Implementation (JI) (e.g., Millar et al., 2007), which may seek to offset carbon emissions, build adaptive capacities of local communities, and provide sustainable development dividends despite mixed results in terms of accomplishing these goals in practice (Corbera and Brown, 2008). Specifically in the case of the CDM, robust empirical research shows overwhelming negative results in win-win terms—while the goal of offsetting carbon emissions has fared better, generating sustainable development dividend has been difficult. For example, after examining 16 existing CDM projects around the world, Sutter and Parreno (2007) found that whereas they could meet 72% of their emissions reduction goals, fewer than 1% might actually contribute significantly to sustainable development in the host country. Furthermore, their research suggests that there might be an actual trade-off between the goals of efficient generation of certified emissions reduction (CERs) and the broader generation of the sustainable development dividend (see also Winkelman and Moore, 2011). Even when relatively successful, triple-win interventions may result in unequal distribution of benefits across mitigation, adaptation, and sustainable development (Bryan et al., 2013). Because relationships among the three goals can lead to both positive and negative consequences, it is important to unravel conditions that lead to desirable outcomes (Chhartre and Agrawal, 2009) (see Section 20.3.3). Moreover, the fact that currently available institutional arrangements that attempt to combine mitigation and sustainable development (such as CDM) are not achieving win-win goals indicates the need for rapidly developing means for evaluating, changing, and improving current policy instruments and mechanisms (Dovers and Hezri, 2010).

Given these connections, there is growing consensus in the literature about a need to integrate development and climate policies; however, the means to achieve this integration differ and are not without controversy (see, e.g., Seballos and Kreft, 2011). An approach often described in the literature is mainstreaming, where governments incorporate climate-related concerns into existing policy (Dovers and Hezri, 2010). A major factor constraining the "mainstreaming" of climate adaptation into development is the disconnect between access to globally available adaptation funds and developing countries' own development agendas (Hardee and Mutunga, 2009; Seballos and Kreft, 2011). This disconnect can potentially inhibit the development of robust local organizations and institutions that effectively integrate or mainstream climate change considerations into development priorities. In particular, research focusing on the National Adaptation Programmes of Action (NAPAs) and the Strategic Programmes for Climate Resilience (SPCRs), designed to support least developed countries to mainstream adaptation, shows that lack of coordination between government sectors, lack of technical capacity, and discrepancies between long-term development goals and short-term adaptation interventions still constrain mainstreaming efforts (Saito, 2013; see also Section 15.2). Even where climate-related initiatives and programs are reasonably well coordinated, bureaucratic complexities can cause communities to be overlooked (Chukwumerije and Schroeder, 2009). For example, in Mexico, despite the governmental discourse supporting climate change policy, actual implementation of mitigation and adaptation actions have been constrained by lack of resources and institutional coordination and limited societal involvement (Sosa-Rodriguez, 2013). Other factors—such as lack of financial and human resources, unclear distribution of costs and benefits, fragmented management, mismatches in scale of governance and implementation, lack and unequal distribution of climate information, lack of institutional memory, and trade-offs with other priorities—may also limit the smooth mainstreaming of climate adaptation action into development (Eakin and Lemos, 2006; Bizikova et al., 2007; Agrawala and van Aalst, 2008; Kok et al., 2008; Metz and Kok, 2008, Sietz et al., 2011). Finally, empirical evidence suggests that the relationship between development variables and climate change responses can be a mixture of positives and negatives, if development variables are not managed well (Garg et al., 2009). For example, in a study of the relationship between malaria incidence, development, and climate variables in India, Garg et al. (2009) found that while some development interventions such as building irrigation canals and dams can, in some cases, increase the incidence of malaria and water-borne diseases (when they exacerbate potential breeding grounds for malarial parasites), others such as higher per capita income can reduce negative health impacts of climate change significantly—although the distribution of benefits can differ between types of interventions (also see Campbell-Landrum and Woodruff, 2006). Understanding how development variables intersect with climate responses is especially important because governments and other actors rarely make decisions in isolation; rather, they respond to multiple stressors both in rural and urban environments (Eakin, 2005; Agrawal, 2010; Wilbanks and Kates, 2010; Lemos et al., 2013). Moreover, some evidence suggests that, in practice, decision makers (from heads of households to policy makers) often do not place climate change at the top of their priority list of critical issues to address (Garg et al., 2007; Kok et al., 2008), although this situation seems to be changing. Moreover, the increasing importance of climatic change in shaping social and governmental policy agendas has resulted in a growing number of examples of specific interventions to respond to climate change, both in developed and developing regions (Ayers and Huq, 2009; Burch, 2010; Bierbaum et al., 2013; for examples of adaptation planning see Chapter 15, especially Section 15.2, and Chapter 14, especially Section 14.3).

20.2.2. Climate-Resilient Pathways

20.2.2.1. Framing Climate-Resilient Pathways

Climate-resilient pathways integrate current and evolving understandings of climate change consequences and conventional and alternative development pathways to meet the goals of sustainable development (see WGIII AR5 Chapter 4). They can be seen as development trajectories that include both mitigation and adaptation, as well as effective development institutions. Climate-resilient pathways represent iterative processes for managing change within complex systems, where unintended consequences are common owing to feedbacks, teleconnections, cross-scale linkages, thresholds, and nonlinear effects (Folke et al., 2002; Scheffer et al., 2009; Lenton, 2011a). Climate-resilient pathways recognize that increasing atmospheric concentrations of GHGs can lead to impacts that have long-term implications for sustainable development. The observed and projected impacts of climate change on poverty and livelihoods, food and water security, health, and human security are well documented in this report (see Chapters 11, 12, 13).

The pursuit of climate-resilient pathways involves identifying vulnerabilities to climate change impacts; assessing opportunities for reducing risks; and taking actions that are consistent with the goals of sustainable development. These actions may involve a combination of incremental and transformative responses that take into account (1) current and anticipated changes in both climate averages and extremes; (2) the dynamic development context that influences social vulnerability, risk perception, conflict resolution, and resilience; and (3) recognition of human agency and capacity to influence the future. This last point is significant, as humans have the capacity to manage risk and to decrease vulnerability through both mitigation and adaptation, as well as through choices of development goals and strategies (IPCC, 2012).

Climate-resilient pathways call for decisions and actions that take into account both short- and long-term time horizons. In the short term, society will have to adapt to changes in the climate that are linked to past emissions, and both incremental and transformative adaptation may thus be significant. Mitigation responses taken in the short term will have a strong influence on climate-resilient pathways for sustainable development in the future, shaping needs for transformative adaptation over a long time horizon. Considering the potential for nonlinear impacts associated with increasing global temperatures, the threats to sustainable development are likely to become greater over time (Wilbanks et al., 2007; Stafford et al., 2010; see also Chapter 12). Discussions of climate-resilient pathways thus cannot be separated from levels of climate change.

20.2.2.2. Elements of Climate-Resilient Pathways

If climate change continues on its current path toward relatively significant impacts (National Research Council, 2010b), climate-resilient pathways will become increasingly challenging, requiring explicit attention to responses in virtually all regions, sectors, and systems to avoid disruptions of development processes. Climate-resilient pathways include two overarching attributes: (1) actions to reduce climate change and its impacts, including both mitigation and adaptation, and (2) actions to ensure that effective risk management institutions, strategies, and choices can be identified, implemented, and sustained as an integrated part of development processes (Edenhofer et al., 2012). Box 20-3 draws on material throughout the chapter to list a number of attributes of climate-resilient pathways categorized into awareness and capacity, resources, and practices. Each of the items is amenable to strategy development in appropriate national, regional, and local contexts. For example, in many cases effective response to extreme events can benefit both from iterative problem-solving and bottom-up engagement in risk management, and from human development to enhance capacities for risk management and adaptive behavior (Tompkins et al., 2008). Folke (2006) characterizes resilience as a process of innovation and development. Pathways should therefore be continuously moving toward a more adapted and less vulnerable state; in some instances,

Box 20-3 | Selected Elements of Climate-Resilient Pathways

Awareness and capacity

- A high level of social awareness of climate change risks
- A demonstrated commitment to contribute appropriately to reducing net greenhouse gas emissions, integrated with national development strategies
- Institutional change for more effective resource management through collective action
- Human capital development to improve risk management and adaptive capacities
- Leadership for sustainability that effectively responds to complex challenges

Resources

- Access to scientific and technological expertise and options for problem solving, including effective mechanisms for providing climate information, services, and standards
- Access to financing for appropriate climate change response strategies and actions
- Information linkages in order to learn from experiences of others with mitigation and adaptation

Practices

- Continuing development and evaluation of institutionalized vulnerability assessments and risk management strategy development, and refinement based on emerging information and experience
- Monitoring of emerging climate change impacts and contingency planning for responding to them, including possible needs for transformational responses
- Policy, regulatory, and legal frameworks that encourage and support distributed voluntary actions for climate change risk management
- Effective programs to assist the most vulnerable populations and systems in coping with impacts of climate change

there may be stages of slow development followed by periods where progress increases speed. Further, the nonlinearity, variability, and uncertainty of climate impacts necessitate a system that allows for the flexibility to adapt to unexpected and even extreme events (Holling, 1973). This is especially true in light of political, economic, or resource constraints, where pathways at the local level will need to be not only flexible but also practical and feasible in both the short term and long term. One of the most challenging aspects of climate-resilient pathways is that they exist in distinctive local contexts, where they are shaped by external linkages that connect them across geographic scales and time. For example, resilience cannot be achieved in a few privileged places if it is not achieved in other connected places, because instabilities in adversely impacted situations will spill over to other situations through such effects as resource supply constraints, conflict, migration, or disease transmission (Wilbanks, 2009; IPCC, 2012, Chapter 7).

Climate-resilient pathways are in fact a process, not an outcome (Manyena, 2006), involving both incremental and transformational changes. The pathways therefore need to be built on a foundation of constantly advancing knowledge, where information is adjusted based on changing scientific knowledge on climate parameters and altering social, economic, and natural resource situations (Berkes, 2007). While some measures will be reactive, the main elements of a pathway are intentional and proactive: anticipating future change and developing appropriate plans and responses. Although payoffs from specific long-term pathways may be unknown, strategies and actions can be pursued now that will contribute significantly to moving toward climate-resilient pathways while helping improve human livelihoods, social and economic well-being, and responsible environmental management (Section 20.6.2).

20.3. Contributions to Resilience through Climate Change Responses

Climate change responses include mitigation, adaptation, and integrated mitigation and adaptation strategies. Related to these responses but generally considered a separate response issue is "geoengineering" (see Box 20-4).

20.3.1. Mitigation

In IPCC's assessment reports, mitigation is the subject of WGIII, to which readers are referred for comprehensive information about options and strategies for reducing GHG emissions and increasing GHG uptakes by the Earth system. For this chapter, the issue is how climate change

Box 20-4 | Considering Geoengineering Responses

If climate change mitigation is not sufficiently successful, policymakers may be faced with demands to find further ways to reduce climate change and its effects.

Such options include intentional large-scale interventions in the Earth system either to reduce the amount of absorbed solar energy in the climate system or to increase the uptake of carbon dioxide (CO_2) from the atmosphere (see Glossary). An example of the former is to inject sulfates into the stratosphere. Examples of the latter include facilities to scrub CO_2 from the air and chemical interventions to increase uptakes by oceans, soil, or biomass (UK Royal Society, 2009; WGIII AR5 Chapter 6; WGI AR5 Chapters 6, 7; see also Chapter 19).

Discussions of geoengineering have only recently become an active area of discourse in science, despite a longer history of efforts to modify climate (Schneider, 1996, 2008; Keith, 2000; Crutzen, 2006). Many of the possible options are known to be technically feasible, but their costs, effectiveness, and side effects are exceedingly poorly understood (National Research Council, 2010b; Goes et al., 2011; MacCracken, 2011; Vaughan and Lenten, 2011). For example, some interventions in the atmosphere might not be unacceptably expensive in terms of direct costs, but they might affect the behavior of such Earth system processes as the Asian monsoons (Robock et al., 2008; Brovkin et al., 2009). Some interventions to increase carbon uptakes, such as scrubbing CO_2 from the Earth's atmosphere, might be socially acceptable but economically very expensive. Moreover, it is possible that optimism about geoengineering options might invite complacency regarding mitigation efforts.

In any case, implications for sustainable development are largely unknown. Even though some views have been expressed that geoengineering is needed now to avoid irreversible impact such as the loss of biodiversity (while many governments have not begun to consider it at all), several countries consider it a research priority rather than a current decision-making option (National Research Council, 2010b). The challenge is to understand what geoengineering options would do to moderate global climate change and also to understand what their ancillary effects and risks might be. This would allow policymakers in the future to respond if severe disruptions appear and, as a result, there is a need to consider rather dramatic technology alternatives. Some observers propose that research efforts should include limited experiments with geoengineering options, but agreement has not been reached about criteria for determining what experiments are appropriate or ethical (Chapter 19.5.4; WGIII AR5 Chapter 3.3.7; Blackstock and Long, 2010; Gardiner, 2010).

mitigation relates to sustainable development, which was addressed by WGII AR4 Chapter 12 (IPCC, 2007a) and is also the focus of WGIII AR5 Chapter 4, including attention to equity issues.

In general terms, mitigation is recognized to be important for sustainable development in two ways (Riahi, 2000). First, it reduces the rate and magnitude of climate change, which reduces climate-related stresses on sustainable development, including effects of extreme weather and climate events (Washington et al., 2009; Lenton, 2011b; IPCC, 2012; see also Section 20.2; Box 20-1). But recent observations of the rate of increase in global carbon dioxide emissions (e.g., Peters et al., 2013) suggest that the challenge of stabilizing concentrations is growing (for further information about international accords, national pledges and inventory reports, and continuing negotiations, along with summaries of current and projected progress with mitigation, see WGIII AR5).

Second, trajectories for technological and institutional change to reduce net GHG emissions interact with development pathways. In some cases, national pledges to achieve mitigation targets (e.g., Figure 20-1) may be congruent with sustainable development in urban settings, such as green growth strategies that reduce local and regional air pollution, enhancing prospects for multilevel governance and integrated management of resources, and encouraging broader participation in development processes (Lebel, 2005; Seto et al., 2010). In other cases, such effects as higher energy prices associated with transitions from fossil fuels to renewable energy sources have the potential to have adverse effects on local and regional economic and social development (IPCC, 2011, Chapter 9).

The challenge for climate-resilient pathways is to identify and implement mixes of technological and governance options that reduce net carbon emissions and at the same time support sustainable economic and social growth in a context where rising demands for economic and social development need to be combined with technology transitions without disrupting the development process. For example, strategies such as increasing carbon uptakes and decreasing carbon losses in the soil through better agricultural management practices—which can reduce net emissions—can improve soil water storage capacity. Practices such as conservation tillage can also increase water retention in drought conditions and help to sequester carbon in soils (Halsnaes et al., 2008). In many cases, however, this challenge remains very difficult to meet.

Mitigation and development also interact in a third way in that different groups and countries' abilities to implement mitigation critically depends on their "mitigative capacity" (Yohe, 2001): their "ability to reduce anthropogenic greenhouse gas emissions or enhance natural sinks" and the "skills, competencies, fitness, and proficiencies that a country has attained which can contribute to GHG emissions mitigation" (Winkler et al., 2007). Here, many of the determinants of mitigative capacity are fundamentally shaped by different countries' levels of development, including their current level of emissions; their stock of human, financial, and technological capital, such as the ability to pay for mitigation; the magnitude and cost of available abatement opportunities; the regulatory effectiveness and market rules; the education and skills base; the suite of mitigation technologies available; the ability to absorb new technologies; and the level of infrastructure development (Box 20-4).

20.3.2. Adaptation

Adaptation is the subject of four chapters of this WGII AR5 (Chapters 14 to 17), to which readers are referred for comprehensive descriptions of concepts, options, strategies, and examples of adaptation practices. For this section, we focus on the intersection between adaptation and sustainable development. Overall, climate adaptation and sustainable development are linked in several ways: first, many of the determinants of adaptive capacity to respond to climate impact and indicators of sustainable development overlap; second, adaptive capacity building may critically contribute to the well-being of both social and ecological systems; and third, building adaptive capacity within a sustainable development framework may require transformational changes (Dovers and Hezri, 2010; Kates et al., 2012; Lemos et al., 2013).

Around the globe, the ability of communities and individuals to respond to climate change is predicated on a number of capacities (e.g., human capital, information and technology, material resources and infrastructure, organizational and social capital, political capital, wealth and financial capital, institutions and entitlements) that typically overlap with indicators of development (Smit and Pilifozofa, 2001; Yohe and Tol, 2002; Eakin and Lemos, 2006). However, building these capacities both in developed and less developed regions has implications for sustainable development because it might increase the consumption of materials and create potential negative effects on ecosystems (e.g., building of new infrastructure and increasing consumption). In terms of governance, climate change adaptation and sustainable development share many characteristics (e.g., issues of spatial and temporal scales, uncertainty, poorly defined jurisdictions; Dovers and Hezri, 2010), and designing and implementing successful interventions require different kinds of capacities, including political and administrative structures (Eakin and Lemos, 2006; Wilbanks et al., 2007). Building adaptive capacity may critically contribute to the improvement of the well-being of both social and ecological systems by bettering livelihoods and reducing pressure

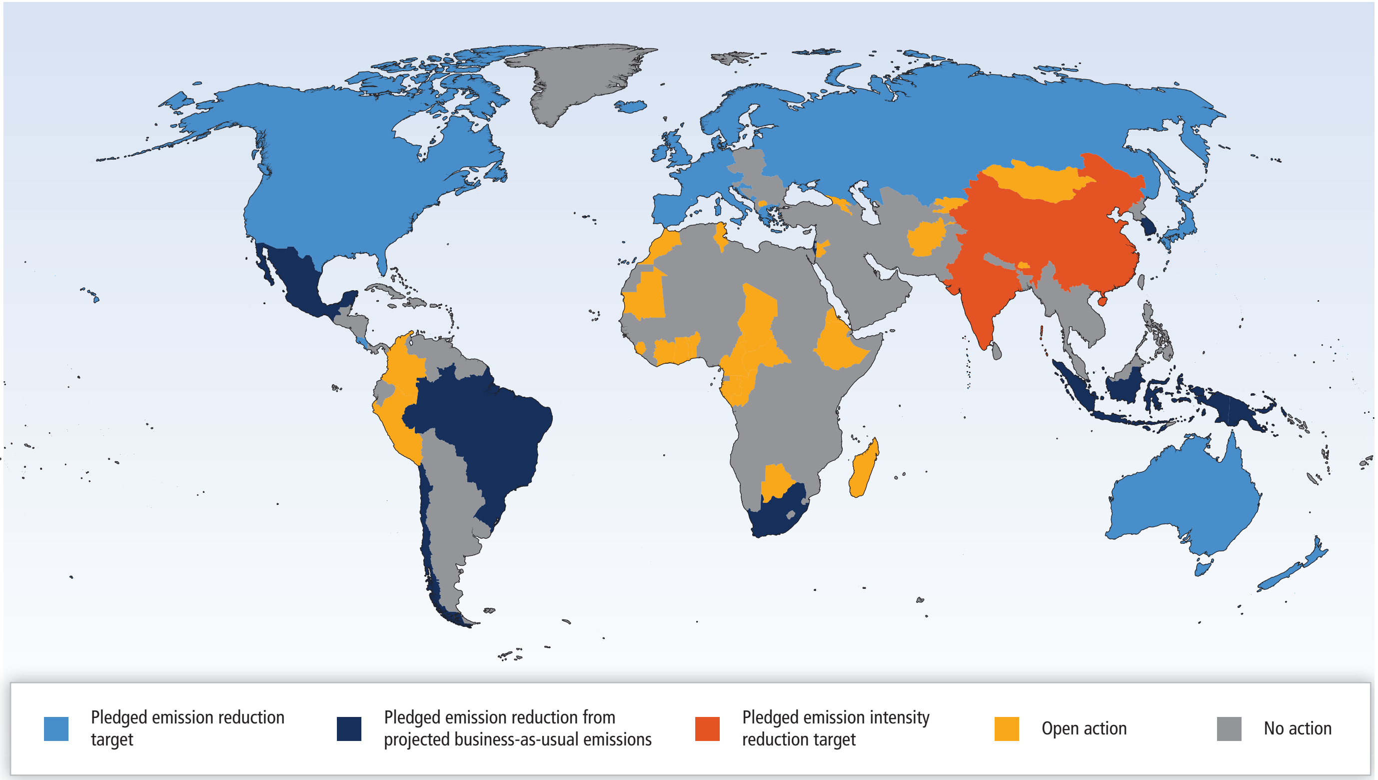

Figure 20-1 | Pledges by Annex 1 and Annex 2 countries in response to the Copenhagen Accord (see http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php, http://unfccc.int/meetings/cop_15/copenhagen_accord/items5265.php). Refer to Table SM21-1 for groupings of countries and territories of the world of relevance for international climate change policy making.

Box 20-5 | Case Studies from China

Water-saving irrigation has enhanced climate change adaptation capacity, improved ecosystem services, and promoted regional sustainable development in China:

- *Water-saving irrigation measures in cropland adaptation to climate change*. Water-saving irrigation is one effective measure to deal with the water scarcity and food security issues caused by climate change (Hanjra and Qureshi, 2010; Tejero et al., 2011). Given an increase in non-agricultural water consumption, China's agriculture could be faced with a severe shortage of water resources (Xiong et al., 2010). Through water-saving irrigation practices, water saved from 2007 to 2009 added up to a total of 61.82–129.66 10^9 m^3, which accounted for 5.6–11.8% of the national total water consumption; total energy saved was equal to 9.59–20.85 Mt of standard coal; and total CO_2 emissions were reduced by 21.83–47.48 Mt of CO_2. Therefore, water saving irrigation has had a positive effect in dealing with climate change and sustainable development (Zou et al., 2012).

Table 20-1 | Water and energy savings and CO_2 emission reductions from water-saving irrigation measures in cropland.

	2007	2008	2009
Water saved (10^9 m^3)	19.37–40.86	19.86–41.55	22.58–47.25
Energy saved (Mt of standard coal)	2.92–6.39	3.08–6.72	3.58–7.73
CO_2 emission reduction (Mt of CO_2)	6.66–14.58	7.02–15.31	8.15–17.59

- *Water-saving irrigation measures in alpine grassland for adapting to climate change*. In recent years, the rise in precipitation and temperature has led to the melting of glaciers and expansion to inland high mountain lakes, contributing to alpine grassland degradation in northern Tibet (Gao et al., 2010). Among many grassland protection measures, alpine grassland water-saving irrigation measures could be effective in redistributing and making full use of increased precipitation and lake water in the dry period, which would reduce the negative effects of climate change and make full use of favorable conditions (Editorial Board of National Climate Change Assessment, 2011; Gao et al., 2012). A 3-year demonstration of alpine grassland water-saving irrigation measures showed that alpine grassland primary productivity nearly doubled while the number of plant species increased from 19 to 29, helping to protect and restore the alpine grassland ecosystem and ecosystem services and to promote regional socioeconomic sustainable development in Northern Tibet (Gao et al., 2012).

on the environment, especially in less developed regions (see Section 20.4.3). Regarding social systems, it is important to consider not only the factors that enable the building of different capacities (e.g., institutions and governance) but also how to guarantee that those who need it the most have access to them (Nelson et al., 2007; Gupta et al., 2010). It is also vital to understand how different capacities influence each other, positively and negatively (Lemos et al., 2013), and how they may affect the long-term resilience of social-ecological systems (Adger et al., 2011; Box 20-5). Indeed, adaptation can be important in reducing stresses on development processes, especially in vulnerable areas where it can help to promote and support sustainable development. For example, where adaptation planning stimulates participatory social processes, including equity and legitimacy, as well as discussions regarding different adaptation options, it can encourage communities to think more clearly about broader sustainable development goals and pathways (National Research Council, 2010a).

Given recent trends in GHG emissions and projections of climate futures that suggest impacts of climate change will be serious and widespread (e.g., Auerswald et al., 2011; Smith et al., 2011), adaptation may require considering transformational changes, in which potentially impacted systems move to fundamentally new patterns, dynamics, and/or locations (Schipper, 2007; Kates et al., 2012; Marshall et al., 2012; Park et al., 2012). Desirable adaptation strategies may vary according to specific kinds of climate change threat, location, impacted system, the geographical scale of attention, and the time frame of strategic risk management planning (Thomalla et al., 2006; Heltberg et al., 2009; National Research Council, 2010a). Transformational adaptation policy at different scales needs to take into consideration the goals of sustainable development, both by fostering positive synergies and by avoiding negative feedbacks between them. This is especially important because some adaptation options might lead to inequitable and unsustainable outcomes, and some adaptations at one scale may negatively affect vulnerability in another (Thomas and Twyman, 2005; Eriksen et al., 2011; Eriksen and Brown, 2011; see also Sections 20.3.3, 20.4.4 and Chapter 14 for a more detailed discussion). For example, in the USA, building adaptive capacity for water management through drought preparedness plans at one scale (the state level) may constrain the flexibility of managers at lower scales (community water systems) to respond successfully to drought (Engle, 2013).

Indeed, adaptation pathways can foster food and water security, human health, and air and water quality and natural resource management, while promoting gender equality and other desirable outcomes consistent with sustainable development goals. However, creating the conditions for the emergence of such outcomes will require better integration in the implementation of policies and programs at all scales. By selecting materials not harmful to the environment, promoting the conservation of energy, water, and other resources, promoting reuse and recycling, minimizing waste generation, protecting habitat, and addressing needs of marginalized groups, adaptation can contribute to win-win and triple-win options that can support a diverse array of development goals (Bizikova et al., 2007; Seto et al., 2010; see also Sections 15.3.1, 20.3.3 and UNFCCC, 2011).

20.3.3. Integrating Climate Change Adaptation and Mitigation for Sustainable Risk Management

Because both adaptation and mitigation are parts of climate-resilient pathways, and because each benefits from progress with the other (e.g., Section 20.2), integrating the two kinds of climate change responses within the broader context of sustainable development has been suggested as an aspirational goal (Wilbanks et al., 2007; Bizikova et al., 2010), especially when policy attention and financial commitments to climate change responses must consider the pursuit of both adaptation and mitigation. In practice, however, mitigation and adaptation tend to involve different time frames, communities of interest, and decision-making responsibilities (IPCC, 2007a; Wilbanks et al., 2007).

Integration of climate change responses with development processes is a further aspirational goal. Recent research suggests that mitigation and adaptation are likely to be more effective when they are designed and implemented in the context of other interventions within the broader context of sustainability and resilience (Wilbanks and Kates, 2010; ADB and ADBI, 2012). Moreover, studies focusing on the intersection between sustainable development and climate policy point out that integration between the two is a desirable although complex path (Section 20.2.1.2; Beg et al., 2002; Robinson et al., 2006; Swart and Raes, 2007; Wilson and McDaniels, 2007; Halsnaes et al., 2008; Ayers and Huq, 2009). Wilson and McDaniels suggest three reasons to integrate across adaptation, mitigation, and sustainable development: (1) many dimensions of the *values* that are important for decision making are common to all three decision contexts; (2) impacts from any one of the three decision contexts may have important *consequences* for the others; and (3) the *choice among alternatives* in one context can be a means for achieving the underlying values important in the others.

A key factor in integrating climate change adaptation and mitigation into sustainable risk management is to understand the processes of decision making at different scales. The distribution of costs and benefits of mitigation and adaptation differ; for example, mitigation benefits are more global, adaptation benefits are often more localized, the research and policy discourses are often unrelated, and the constituencies and decision makers are often different (mitigation may involve powerful industrial stakeholders from the energy sector concentrated at higher levels of decision making, while adaptation may involve more dispersed stakeholders at the local level across sectors) (Wilbanks et al., 2007). To significantly reduce total global emissions, mitigation decisions must be taken either by major emitters, or by groups of countries. At the national and international level, direct responsibilities to curb the main drivers of global climate change are dispersed across countries (Banerjee, 2012). In contrast, adaptation often falls to practitioners where local responsibility is clearer, although it often depends on support from national and global scale (Tanner and Allouche, 2011).

In many cases, the challenge of fostering synergies while avoiding negative feedbacks often comes into focus in place-based discussions of climate change responses and development objectives such as localities and small regions (Dang et al., 2003; Wilbanks, 2003; Bulkeley and Schroeder, 2012). Globally, a particular hurdle is the practice of applying available mitigation resources only for reducing emissions beyond that which would have occurred without those resources ("*additionality*"), when access to resources for adaptation efforts should take into account the critical role of *co-benefits* in supporting development in other ways while at the same time reducing vulnerabilities to climate change impacts (National Research Council, 2010a; see also Section 20.4.1).

Choices in integrating adaptation and mitigation will vary according to the circumstances of each country and each locality (Wilbanks, 2003; De Boer et al., 2010). In highly vulnerable countries, adaptation may be seen as the highest priority because there are immediate benefits to be obtained by reducing vulnerabilities to current climate variability and extremes as well as future climate changes. In the case of developed countries, adaptation initiatives have often been seen as a lower priority because it is perceived that there is abundant adaptive capacity (Naess et al., 2005). Yet major losses and damages in some industrialized countries related to climatic variability and extremes challenge this perception (e.g., Hurricane Sandy, tornadoes, and drought in the USA in 2011 and 2012). Mitigation may be seen as more acute political question—involving well-organized stakeholders concerned about costs—in countries that contribute a large proportion of GHG emissions (e.g., National Research Council, 2011), and it may be seen as an investment opportunity for the domestic private sector.

As indicated above, one emerging strategy to integrate climate and development policies is the design of "win-win" and "triple-win" interventions that seek to achieve an appropriate mix of mitigation and adaptation within the context of sustainable development (Pyke et al., 2007; Swart and Raes, 2007). Swart and Raes suggest a number of factors that should be taken into consideration when evaluating combined adaptation and mitigation policy designs, including (1) avoiding trade-offs, when designing policies for mitigation or adaptation; (2) identifying synergies; (3) enhancing response capacity; (4) developing institutional links between adaptation and mitigation, for example, in national institutions and in international negotiations; and (5) mainstreaming adaptation and mitigation considerations into broader sustainable development policies. Box 20-5 provides a case study of an initiative in China that has been a winner for both climate change responses and regional sustainable development. The potential for climate-resilient pathways may already be limited, however, in part because of path dependency stemming from choices on mitigation, adaptation, and political interpretations and subsequent choices around "sustainable" development (Swart et al., 2003; Barker, 2008); and, in many cases, interventions have not delivered win-win results, which raises questions about the actual attainability of win-win strategies given legal, political, economic, and/or institutional obstacles (Warner et al., 2012b; see also Section 20.2.1.2).

In synthesizing evidence from a series of empirical articles focusing on the intersection between mitigation and adaptation (M&A), Wilbanks and Sathaye (2007) argue that M&A pathways might be alternatives in reducing costs, complementary to and reinforcing each other (e.g., improvements in building energy efficiency), or competitive and mutually contradictory (e.g., coastal protection vs. reductions in sea level rise). In Bangladesh, for example, waste-to-compost projects contribute to mitigation through reducing methane emissions; to adaptation through soil improvement in drought-prone areas; and to sustainable development through the preservation of ecosystem services (Ayers and Huq, 2009; also see Vergara et al., 2012, regarding possible development benefits of mitigation and adaptation in Latin America and the Caribbean). Land management and forestry activities contribute to ecosystem-based mitigation, for example, through the reduction of emissions from deforestation and forest degradation, and adaptation, for example, through the conservation of hydrological services provided to people facing water problems, as well as renewable energy (see several cases of ecosystem-based adaptation in Pramova et al., 2012). However, trade-offs are also possible, for example, if ecosystem management for mitigation purposes reduces the livelihood opportunities and the adaptive capacity of local people (Locatelli et al., 2011). The scale of these examples is often local, however, and longer term success of these pathways will depend on the broader context of mitigation and facilitation of adaptation options (Metz et al., 2002).

When integrating across the goal of finding climate-resilient pathways (and win-win solutions), decision makers often need to address issues of scale, along with trade-offs in values such as economic profitability versus stability of food and livelihood security (e.g., in agricultural policy), relationships between development ends and means, uncertainty and path dependencies, and institutional complexity (Tol, 2004; Klein et al., 2005; Wilson and McDaniels, 2007). They also need to consider the possibility of ancillary co-benefits, complementarities and potential contradictions, opportunity costs, and unknown negative and positive feedbacks (e.g., interactions among options and paybacks (Rosenzweig and Tubiello, 2007; Swart and Raes, 2007; Wilbanks and Sathaye, 2007; Kok et al., 2008; IPCC, 2007a, Chapter 18; National Research Council, 2010a)). Current research is examining trade-offs and complementarities between mitigation and adaptation in different sectors. In the energy sector, for instance, Kopytko and Perkins (2011) have examined to what extent the siting of nuclear power plants might constrain future adaptation to sea level rise. Others ask about such issues as adaptation implications of the production of biofuels (La Rovere et al., 2009); agriculture and water (Rosenzweig and Tubiello, 2007; Shah, 2009; Falloon and Betts, 2010; Rounsevell et al., 2010; Turner et al., 2010); conservation (Rounsevell et al., 2010; Turner et al., 2010); use of mitigation programs to finance adaptation (Hof et al., 2009); and the urban environment (Biesbroek et al., 2009; Hamin and Gurran, 2009; Roy, 2009; Romero-Lankao and Wilbanks, 2011; Viguié and Hallegatte, 2012).

20.4. Contributions to Resilience through Sustainable Development Strategies and Choices

Although climate change responses can contribute significantly to climate-resilient development pathways, some of the key elements of resilience lie in sustainable development implementation, which can make resilience either more or less achievable. Examples of ways that development strategies and choices can contribute to climate resilience include being capable of resolving trade-offs among economic and environmental goals (e.g., Bamuri and Opeschoor, 2007), ensuring effective institutions in developing, implementing, and sustaining resilient strategies, and enhancing the range of choices through innovation (e.g., Folke et al., 2002; Chuku, 2009; Hallegatte, 2009).

20.4.1. Resolving Trade-offs between Economic and Environmental Goals

Sustainable development pathways will be more climate resilient if they develop and utilize socioeconomic and institutional structures that are effective in resolving trade-offs among social, economic, and environmental goals—a central tenet of sustainable development (Section 20.2.1.1). As climate change poses risks to goals such as poverty reduction, food and livelihood security, human health, and economic prosperity (Chapter 19), societies face the task of defining how to manage these risks and what levels of risk without compromising what they value most and what defines their societies. The management of risk—and the weighting of various categories of risk—depends on social definitions of what consequences are acceptable, tolerable, or intolerable (Chapter 16).

There is a long-standing assumption that economic growth is in conflict with environmental management (Victor and Rosenbluth, 2007; Hueting, 2010). Much of this thinking can be traced back to Malthus and his assertions that population growth (and associated consumption) would expand at an increasing rate until the limits of the Earth's capacity were reached (Malthus, 1798). The very idea of sustainable development itself springs from a need to respond to such Malthusian ideas. The views expounded in the Brundtland Report, for example, are that development should not be unconstrained but should rather be modified into a "sustainable" form (WCED, 1987). Views about relationships between economic growth and environmental protection range widely from arguments that sustainable development is inconsistent with continued economic growth (e.g., Robinson, 2004) to arguments that economic growth and associated technological innovation can enhance options for environmental management (Lovins and Cohen, 2011). Relationships between affluence and environmental protection are complex, as poverty can lead to land degradation and affluence can afford support for nature preservation, while economic growth is built on levels of resource extraction and use that require significant changes in environments. Sustainable development cannot escape continuing tensions between economic growth and environmental management goals, where strongly held views across society often differ so fundamentally that conflict results unless social processes and institutional mechanisms are effective in resolving a host of trade-offs (Boyd et al., 2008), with both values and processes varying according to development context.

Examples of frameworks of thought often related to addressing trade-offs are multi-metric valuation and co-benefits (see also Ness et al., 2007, regarding tools for sustainability assessment; Bizikova et al., 2008, Appendix 1; Gulledge et al., 2010):

- *Multi-metric valuation*. In evaluating development pathways, there are often needs to combine a number of dimensions associated with different valuation metrics and information requirements, such as monetary measures of returns and non-monetary metrics of risk.

Fields ranging from aquatic ecology to risk assessment and financial management have developed tools for such complex valuations, including graphical mapping (e.g., Sheppard and Meitner, 2005; Rose, 2010; Moed and Plume, 2011; UNFCCC, 2011) and the construction of multi-metric indexes (e.g., Johnston et al., 2011). Multi-metric indicators have been widely studied and critiqued, and they are an active topic of research (e.g., Drouineau et al., 2012; Schoolmaster, 2013). A key challenge is weighting different valuations being combined quantitatively, which may be addressed in part by constructing multiple indices. More commonly in collective decision making, however, analytical-deliberative group processes are used to evaluate, weight, and combine different dimensions and metrics qualitatively (National Research Council, 1996).

- *Co-benefits*. An issue in both climate and development policy, related in some cases to access to financial support (e.g., Miller, 2008), is the fact that a specific resilience-enhancing action may have benefits for both development and for addressing concerns about climate change. International funding for mitigation projects has often adopted the concept of "additionality," which takes the position that financial support should be limited to those climate change response benefits that are *in addition to* what would be happening in development processes otherwise (e.g., Muller, 2009). This general concept (e.g., "incremental" costs and benefits) has been applied in financial support for adaptation as well. A co-benefits approach, on the other hand, takes the position that actions that benefit *both* development and climate change responses simultaneously should be encouraged and that a combination of both kinds of benefits should increase the attractiveness of a proposed action (Section 20.3.3). Co-benefits of mitigation actions, such as health benefits, have been extensively analyzed (e.g., Younger et al., 2008; Netherlands Environmental Assessment Agency, 2009; WHO, 2011; EPA, 2012), and they are being actively explored for adaptation as well (e.g., National Research Council, 2010a; UNFCCC, 2011).

As an example of co-benefits, mechanisms such as REDD+ have the potential to achieve both carbon emissions reduction and to benefit livelihoods of those living in forested areas, as well as supporting benefits to social equity (Anglesen et al., 2009; UNEP, 2013). As one instance, the government of Ethiopia has recognized the multiple benefits that can be derived and has incorporated a REDD+ initiative in critical sectors of the economy to develop an environmentally sustainable growth path in Ethiopia (FDRE, 2011). Tools for analyzing such issues are associated with research on "externalities" (e.g., Baumol and Oates, 1988; Klenow and Rodriguez-Clare, 2005; also see Chapter 17 and multi-metric valuations above), but participative planning and decision making usually incorporate a co-benefits perspective as a matter of course.

In practice, trade-offs between different development goals (Stoorvogel et al., 2004) may or not be resolved in coherent ways (Metz et al., 2002). In many cases, resolutions emerge through untidy social processes of evolution and attrition, reflecting dynamics of values, power, control, and surprises, rather than through formal analysis (Bizikova et al., 2008). In some cases, trade-offs are addressed with the assistance of scenario development, the creation of descriptive narratives, and other projections of future contingencies (IPCC, 2012, Chapter 8), along with participative vulnerability assessments (National Research Council, 2010a).

20.4.2. Ensuring Effective Institutions in Developing, Implementing, and Sustaining Resilient Strategies

Climate-resilient pathways will benefit from institutions that are effective and flexible in the face of a wider range of challenges, of which climate change is only one (Gupta et al., 2010). Governance systems, including public and private organizations, will need resources (e.g., human, financial, political, technological) to enable vulnerable societies that are sensitive to the impacts of climate change to transform their lives. Effective management of natural capital and ecosystem goods and services can be accomplished only where there are strong institutions as stewards and a regulatory force to ensure that vulnerable communities are protected from climate shocks and stresses and that growth from climate change is inclusive (Mitchell and Tanner, 2006). Moderating the impacts of climate change will also require strong a foundation in science and technology; but the deployment of science and relevant technologies cannot take place in a vacuum. It will need effective institutional arrangements to bolster both adaptation and mitigation demands and to combine technology options with local knowledge (Section 20.4.3).

"Institutions" refer not only to formal structures and processes but also to the rules of the game and the norms and cultures that underpin environmental values and belief systems (see Glossary). Ostrom (1986) defines institutions as the rules, norms, and practices defining social behavior in a particular context—the action arena. Institutions define roles and provide social context for action and structure social interactions (Hodgson, 2003). Definitions of sustainability are shaped largely by institutional values, cultures, and norms. Institutions also critically influence our ability to govern and manage the resources and systems that shape adaptation, mitigation, and sustainable development. Fostering climate-resilient pathways requires strong institutions that are able to create an enabling environment through which adaptive and mitigative capacities can be built (IPCC, 2007a, Chapter 20; Gupta et al., 2010). Implicit in institutional resilience is the capacity of the exposed unit and the players within an action arena to devise rules that allows them to recover from environmental shocks, and equally ones that provide incentives and benefits that equitably distribute resources across social groups (Handmer and Dovers, 1996; McSweeny and Coomes, 2011). Hence, the trajectory to a climate-resilient pathway requires institutional arrangements that foster innovation, monitoring, and evaluation of strategies for managing climate impacts and reducing risks.

Transformative action within a framework of climate-resilient pathways is rooted in strong and viable institutions and in an institutional context that adaptively manages the allocation of resources and processes of change. Institutions at different levels are the object of societal pressures and challenges relating to environmental change. Local institutions are particularly adroit in coping with multiple changes. These changes often force local actors and organizations to rethink their institutional arrangements and make adjustments that will allow them to cope with multiple vulnerabilities (McSweeny and Coomes, 2011), and their bottom-up initiatives are critically important to climate-resilient pathways. Organizational mechanisms are central to building linkages between local level adaptation action and national level planning. In six case studies in West Africa and Latin America, Agrawal et al. (2011) found that these connections are missing in all the countries studied. However, in these countries external policy support catalyzed adaptation actions through three types of intervention mechanisms: information, incentives, and institutions.

Local institutions crucially influence the ability of communities to adapt and benefit from adaptation and mitigation programs in rural and urban settings (Corbera and Brown, 2008; Chhartre and Agrawal, 2009; Agrawal, 2010). For instance, institutions tend to play an influential role in shaping farmers' decisions and helping them make strategic choices with several implications for livelihoods and sustainable development (Agrawal, 2010). In rural areas, current socioeconomic dynamics, rapid population growth, commercialized agriculture, new agricultural trends, and technological advancements in agriculture have meant that local organizations and actors have seen a change in their role managing environmental resources; local institutions are themselves in a state of flux as they are subjected to uncertainties in climatic condition (Senaratne and Wickramasinghe, 2010). However, in developing countries, particularly in Africa, where traditional knowledge could potentially moderate this uncertainty, it is often not recognized as a reference point for managing climate risks and emerging threats. In Kenya, the importance of indigenous knowledge, given increased uncertainty and climate-related risks, has compelled national agencies such as the Kenyan Meteorological Agencies and vulnerable groups such as the indigenous communities commonly known as rainmakers to form strategic reciprocal links. By working closely together to calibrate their forecasts and test the efficacy of the results against climate change impacts on agricultural productivity, the two groups have been able to demonstrate the benefits of Western science and traditional knowledge systems to increase effectiveness (Ziervogel and Opere, 2010). In integrating different kinds of knowledge, participatory processes, which call for a deliberative form of decision making among stakeholders, are well suited to the governance culture necessary for effective adaptation and mitigation. However, findings in the literature regarding the effectiveness of participatory processes are mixed. For example, though some scholars have argued that deliberative democracy methods can bring diverse stakeholders and kinds of knowledge (e.g., lay, expert, and indigenous) together thus putting in place a more communicative model of science delivery (Benn et al., 2009), empirical research shows that stakeholder participation does not always lead to consensus (Rowe and Frewer, 2004; Bell et al., 2011; also see Salter et al., 2010).

In addition, better institutions are needed to handle the large flows of funds and other resources that are associated with managing and improving the delivery systems that will allow people and organizations to take advantage of opportunities that will trigger a set of actions to combat the negative impacts of climate change. The complexity of different resource flows and distributional effects related to adaptation and mitigation is at the heart of the sustainable development debate, with numerous implications for equity and justice (O'Brien and Leichenko, 2003; Roberts and Parks, 2006). The nature and dynamics of climate change call for flexibility to "allow society to modify its institutions at a rate commensurate with the rapid rate of environmental change" (Gupta et al., 2008). Here, institutional "renewal" is essential to achieve a degree of social cohesion and transformation.

An institutional response to climate change is even more fundamental in common pool property resources such as freshwater, especially because in a changing climate, many river basins are subjected to increased precipitation or water scarcity that affects both their ecosystems and the resources that support the livelihoods of those communities dependent on them. The quality and performance of the organizations and mechanisms created to manage these resources are largely shaped by the rules they follow and the suitability of these rules to the social ecological system in which they are embedded (Bisaro et al., 2010). Indeed, a climate-resilient pathway is one that will not only manage biophysical changes, but also address inherent institutional asymmetries that can further reinforce current inequalities in the way common pool resources are managed. In this context, the monitoring and mediation capacities and the degree to which resource management organizations are embedded at different scales across the governance regime will largely shape its adaptive capacity and sustainability. Thus, the vulnerability of large river basins will largely depend not only on the changing biophysical conditions, but also on institutional architecture that is put in place to manage risks and build resilience. For example, Schlager and Heikkila (2011) argue that compacts that have fixed allocation rules tend to exhibit greater vulnerability to climate change mainly because the system is far too rigid and does not allow for much flexibility in dealing with the changing hydrologic regime. States such as Colorado in the USA have dealt with water scarcity more efficiently mainly because users of the basin have access to venues that allow them to design and review current rules (Schlager and Heikkila, 2011).

Common problems with institutional arrangements for adaptively managing natural resources include a frequent incompatibility of current governance structures with many of those that may be necessary for promoting social and ecological resilience. For example, some major tenets of traditional management styles have "in many cases operated through exclusion of users and the top-down application of scientific knowledge in rigid programmes" (Tompkins and Adger, 2004, p. 10).

20.4.3. Enhancing the Range of Choices through Innovation

Finally, climate resilience will in most cases depend on innovation, developing new ideas and options or adapting robust familiar ideas and options to meet emerging new needs and to respond to surprises (see also WGIII AR5 Chapter 6). As indicated in the previous section, integrated strategies for climate resilience can benefit from considering possibilities to develop new options through social, institutional, and technological innovation. For example, if a climate-resilient pathway for a particular region calls for coping with greater water scarcity, innovations might consider changes in water rights practices, improving the understanding of groundwater dynamics and recharge, improving technologies and policies for water use efficiency improvements, and in coastal areas the development of more affordable technologies for desalination (Lebel, 2005; National Research Council, 2010a). One key issue for risk management, therefore, is assessing needs for and possible benefits from targeting innovation efforts on critical vulnerabilities.

Innovations can include both technological and social changes, which in many cases are closely related (Rohracher, 2008; Raven et al., 2010), as technology and society evolve together (Kemp, 1994). An important characteristic of such socio-technical transitions are the interactions and conflicts between new, emerging systems and established regimes, with strong actors defending business-as-usual (Kemp, 1994; Perez, 2002; IPCC, 2012).

Effective use of innovations depends on more than idea and/or technology development alone. Unless the innovations, the skills required to use them, and the institutional approaches appropriate to deploy them are effectively transferred from providers to users, effects of innovations—however promising—are minimized (IPCC, 2012). Challenges in putting science and technology to use for sustainable development have received considerable attention (e.g., Nelson and Winter, 1982; Patel and Pavit, 1995; National Research Council, 1999; International Council for Science, 2002; Kristjanson et al., 2009). These studies emphasize the wide range of contexts that shape both barriers and potentials and the importance of "co-production" of knowledge, integrating general scientific knowledge with other forms of knowledge (e.g., local, indigenous, practical knowledge, experience, and expertise). If obstacles related to intellectual property rights can be overcome, however, the growing power of the information technology revolution could accelerate the transfer of technologies and other innovations (linked with local knowledge) in ways that would be very promising for strengthening local resilience (Wilbanks and Wilbanks, 2010).

New technologies have the potential to allow a number of developing countries to benefit from knowledge in ways that will give them considerable advantage in building the relevant social and institutional infrastructure to sustain a climate-resilient pathway. Advances in mobile technologies in developing countries, for example, have increased the accessibility of farmers to critical information such as disease surveillance, information related to agricultural inputs, and market prices for crops (Hazell et al., 2010; Juma, 2011). Biotechnology applications in biological systems have the potential to lead to increased food security and sustainable forestry practices, as well as improving health in developing countries by enhancing food nutrition.

20.5. Determinants of Resilience in the Face of Serious Threats

Climate change is not the only type of change occurring in the 21st century. Many households, communities, organizations, countries, and regions are confronting a confluence of economic, political, demographic, social, cultural, and environmental changes. Issues such as poverty, economic crisis, increasing inequality, and violent conflict often draw attention away from concerns about climate change, the loss of biodiversity and ecosystem services, and other global environmental issues. However, the impacts of climate change and extreme events can exacerbate food insecurity, slow down the pace of poverty reduction in urban areas, influence human health, and jeopardize sustainable development (Chapters 11, 12, 13). Resilience is a concept that takes into account how systems, communities, sectors, or households deal with disturbance, uncertainty, and surprise over time, and it is characterized by both adaptability and transformability (Walker and Salt, 2006; Folke et al., 2010; Westley et al., 2011). The sections below consider two important components of climate-resilient pathways: transformational adaptation in response to the impacts of climate change, and transformational change to reduce vulnerability and the risk of high-magnitude climate change.

20.5.1. Relationships between the Magnitude and Rate of Climate Change and Requirements for Transformational Adaptation

The timing and ambition levels of global GHG mitigation efforts will influence the magnitude and rate of climate change and its impacts, particularly in the second half of the 21st century and beyond (Kriegler et al., 2012; Peters et al., 2013; Rogelj et al., 2013; see also Box 20-3). Model results based on integrated scenarios that take into account geophysical, technological, social, and political uncertainties indicate that reaching the often-discussed limit of a 2°C average global temperature increase calls for mitigation of emissions through increased energy efficiency and lower energy demand well before 2020 (Peters et al., 2013; Rogelj et al., 2013; see also Section 20.6.1). If the magnitude and rate of climate change is kept minimal or moderate, incremental adaptation may be a sufficient response to consequences in many locations and contexts. However, in cases where vulnerability is currently high, transformational adaptation may be needed to respond to changes in climate and climate variability. In the absence of ambitious mitigation efforts, the impacts of climate change can be expected to increase dramatically from the second half of the 21st century onward (see Chapter 19). In this case, transformational adaptation may be required in advance of disruptive impacts to reduce risks and vulnerabilities (Kates et al., 2012).

This distinction between incremental and transformational adaptation is important: incremental adaptation can be considered extensions of actions and behaviors that already are in place to reduce losses or enhance benefits associated with climate change, often where the goal is to maintain the essence and integrity of an existing system or process at a given scale (Kates et al., 2012; Park et al., 2012). Transformational adaptation, in contrast, includes actions that change the fundamental attributes of a system in response to actual or expected impacts of climate change. These may involve adaptations at a larger scale or greater intensity than previously experienced; adaptations that are new to a region or system; or adaptations that transform places or lead to a shift in the location of activities (Kates et al., 2012). Such transformations are expected to occur when the rate and magnitude of climate change threatens to overwhelm the resilience of existing systems, or when vulnerability is high (Kates et al., 2012). Transformational adaptation often occurs in continuous interaction with incremental adaptations (see IPCC, 2012, Figure 8-1; Park et al., 2012). Although thresholds or tipping points in complex systems are difficult to predict, studies from a variety of disciplines indicate some generic properties associated with transitions between different states, including an increase in recovery times from disturbances such as extreme weather events (Scheffer et al., 2009; Lenton, 2011a). The risks associated with a high magnitude and rate of climate change and its impacts on natural and managed resources and systems are considerable. The limits to adaptation (Chapter 16) suggest that transformational change may be a requirement for sustainable development in a changing climate (Westley et al., 2011; O'Brien, 2012).

20.5.2. Elements of and Potentials for Transformational Change

Transformational change can be considered a means of reducing risk and vulnerability, not only by adapting to the impacts of climate change, but also by challenging the systems and structures, economic and social relations, and beliefs and behaviors that contribute to climate change and social vulnerability. In cases where current development pathways are considered as the root causes of climate risk and vulnerability, transformation of wider political, economic, and social systems may be necessary (Pelling, 2010; IPCC, 2012; Lemos et al., 2013).

Transformation is defined as a change in the fundamental attributes of natural and human systems (see Glossary). Within the WGII AR5, transformation could reflect strengthened, altered, or aligned paradigms, goals, or values towards promoting adaptation for sustainable development, including poverty reduction. Transformations can occur quite suddenly, in response to a specific event or a momentous incident, or they may emerge gradually over time (Loorbach, 2007). Transformational change is often difficult to order or plan, and there are many social, political, and cultural barriers and resistances. Transformational change can threaten vested interests, or prioritize the interests of some over the well-being of others, and it is never a neutral process (Meadowcroft, 2009; Smith and Stirling, 2010). At the national level, transformation is considered most effective when it considers a country's own visions and approaches to achieve sustainable development in accordance with their national circumstances and priorities. While not every transformation is considered ethical, equitable, or sustainable, it is possible to promote deliberate transformations that reduce climate risk and vulnerability and contribute to global sustainability (Folke et al., 2010; Kates et al., 2012; O'Brien, 2012).

There is an extensive literature on transitions and transformations covering a variety of sectors and factors that influence changes in systems and behaviors (Geels, 2002; Calvin et al., 2009; Berkhout et al., 2010; Pelling 2010; Shove and Walker, 2010; WGIII AR5 Chapter 6). Transformations can be promoted by creating enabling conditions, which include a supportive social environment, information flows, and access to options, resources, and incentives for change (Kates et al., 2012). Transformations can also be stimulated through rules and regulations that necessitate innovations, alternative options, or new behaviors. Finally, transformations may result when alternative systems and structures eventually make old ones seem outdated. Often, dramatic focal events can draw attention to the need for change and mobilize groups or networks to advocate transformational change (Hernes, 2012).

Transformation processes are linked to learning, leadership, empowerment, and collaboration within and across institutions, organizations, and groups (Heifetz et al., 2009; IPCC, 2012, Chapter 8; Kates et al., 2012; O'Brien, 2012). Other key elements associated with transformations include adaptable institutions (cultural, economic, and governance), all types of capital, diversity in landscapes, seascapes and institutions, learning platforms, collective action and networks, as well as reflexivity and the capacity to take different perspectives (Loorbach 2007; Folke et al., 2010; Schlitz et al., 2010; Westley et al., 2011). Many of the elements of climate-resilient pathways discussed in Box 20-3 can, in fact, support transformation.

Transformations can take place within diverse realms or spheres (see Figure 20-2). Within each sphere, there exist both catalysts and constraints to transformation. The core of transformational change occurs in what is labeled in Figure 20-2 as the "practical sphere." Here,

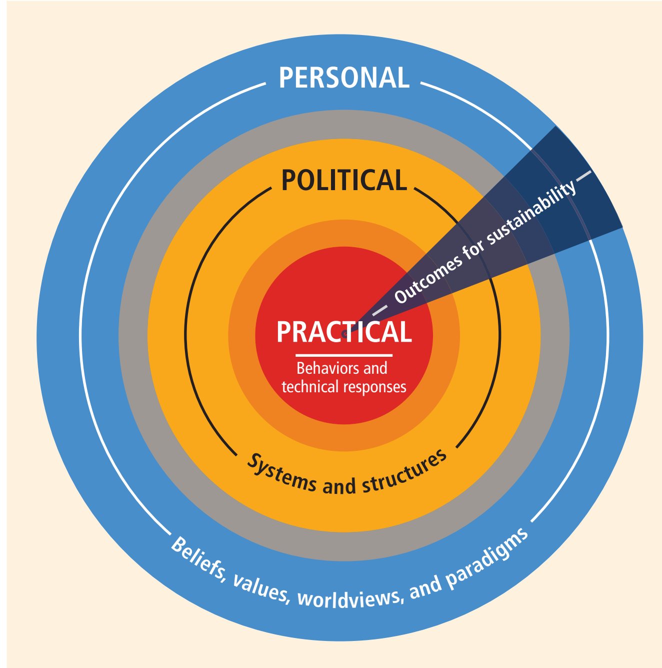

Figure 20-2 | The three spheres of transformation. Transformational change may be an effective leverage point for promoting climate-resilient pathways for sustainable development. This figure depicts three interacting spheres or realms where transformational changes toward sustainability may be initiated. Transformations in the outer two spheres can have a large influence on behaviors and technical responses, contributing to nonlinear transformations to sustainability (O'Brien and Sygna, 2013).

measures such as technological innovations and economic incentives are used to influence sustainable behaviors and responses. The outcomes of transformations in this sphere are observable and measurable; many sustainability policies and initiatives target transformations in this sphere. However, these transformations are often constrained by larger systems and structures, including financial, political, legal, social, economic, ecological, and cultural systems that define the boundaries for action. The "political sphere" is where systems and structures are transformed (intentionally or unintentionally) through politics and social movements, or through changes in social and cultural norms and power relations. Systems and structures often reflect dominant cultural beliefs and worldviews, and it is here where value conflicts may be experienced or resolved. A third sphere of transformation is the "personal sphere," which includes individual and collective beliefs, values, and worldviews, as well as the dominant paradigms. Transformations in this sphere can influence systems, structures, behaviors, and responses, and thus they represent important leverage points for sustainability. Attention to transformations in all three spheres is considered necessary in response to the observed and anticipated impacts of climate change (Beddoe et al., 2009; O'Brien and Sygna, 2013).

20.6. Toward Climate-Resilient Pathways

20.6.1. Alternative Climate-Resilient Pathways

Climate-resilient pathways consist of future trajectories of development that combine adaptation and mitigation in the context of sustainable development implementation. At any scale (local or regional) there are alternative paths leading to similar levels of climate resilience (Holling, 1973). At any time along a pathway, more or less resilience may be observed at specified points within the system (or locality), while the total amount of resilience within the entire system remains unchanged (Folke, 2006). Each potential alternative pathway can be strengthened and evaluated based on certain risk management characteristics/elements: the capacity to (1) foresee risk/vulnerability; (2) decrease climate change impacts; (3) respond rapidly to unpredictable, uneven, and extreme events; (4) include considerable amounts of proactive adaptation; and (5) evolve in support of societal advancement and balanced environmental management.

Examples in this chapter demonstrate that many of the choices involved in framing and supporting attempts to increase and sustain climate resilience are made largely at global and national levels, but many of the actions to sustain resilience are made at local levels. The global pathways that emerge are accumulations of these local and national choices. In these processes, path dependence is strong enough such that risk management decisions in the near term are more likely to lead to resilience if long-term objectives are included as well as a wider spatial scale up to and including the global level.

A central issue in considering alternative pathways is the extent to which they may fail to meet a criterion of climate resilience. Or to put the question more simply, "are there any boundaries on the envelope of climate resilience?" The answer is highly scale dependent. We have a carbon legacy in the atmosphere, and total prevention/avoidance of impacts is now unachievable (Dickinson, 2007). At any level of stabilization of GHG concentrations, with even the strongest emissions reduction targets, some localities or systems or populations will be vulnerable to disruptions because there is in effect no limit below which universal prevention of residual loss and damages can be assured. Transformational change will therefore need to be a key component in nearly all alternative climate-resilient pathways.

In the event that global surface mean temperatures rise through +2°C to +4°C and higher (Anderson and Bows, 2008; Schneider, 2008; New et al., 2012), sustainability will become significantly more difficult to achieve (food security is a notable example; see Chapter 7). For example, a business-as-usual future society where unsustainable development paths are the norm, where technology transfer between countries is lacking, population growth increases rapidly, GHG emission go unabated, and institutions and governance structures are ineffective at creating effective climate change policies, would almost certainly result in losses so widespread that a development pathway would not be resilient (Riahi et al., 2011; Arnell et al., 2013). A pathway that included these elements would fall outside the "boundaries of the envelope of climate resilience."

Within these boundaries, climate-resilient pathways can be made up of a collective of alternative choices at the regional level, where they are dependent upon specific demographics, potentials for economic development and growth, ecological and ecosystem services, access to natural resources, institutional and governance structures, and technological development and transfer. This concept at the global level offers a conceptual framework for considering alternative mixes of actions in support of climate resilience. Pathways can be developed to illustrate a range of possible futures, as a basis for discussion, following different yet distinct storylines. These dimensions can then be related to socioeconomic challenges confronting climate change mitigation and adaptation (as one aspect of sustainable development). One such pathway could have relatively limited challenges to both adaptation and mitigation, while another has substantial challenges to both adaptation and mitigation. Any pathway characterized by low challenges to both has a high potential to be more climate resilient at the global scale and in many local or national situations. A pathway characterized by high challenges to both adaptation and mitigation has a high potential to be less climate resilient at the global scale and in many localities and countries.

20.6.2. Implications for Current Sustainable Development Strategies and Choices

Decision makers face an array of choices in their efforts to define and implement pathways that will help to improve human well-being now and in the future in the face of climate change and other stressors.

Although payoffs from specific long-term pathways may be uncertain at this time, growing evidence (IPCC, 2007; see also Chapters 8 to 13, 16 to 19) suggests that decision points and actions are at hand now. Climate-resilient development pathways are not only about actions taken in the future, but they are also about strategies and choices that are taken today. In fact, damage and loss patterns are not limited to future vulnerabilities; in many areas they are impeding food production and other essential development services in ways that deepen and widen poverty (Chapter 13), contribute to involuntary migration (Chapter 12; Warner and Afifi, 2013), and pressure food production and food prices (Chapters 7, 17; Warner and van der Geest, 2013).

In this sense, delaying action in the present may reduce options for climate-resilient pathways in the future. In some parts of the world,

Frequently Asked Questions

FAQ 20.4 | Are there things that we can be doing now that will put us on the right track toward climate-resilient pathways?

Yes. Climate-resilient pathways begin now, because it is time to consider possible strategies that would increase climate resilience while at the same time helping to improve human livelihoods and social and economic well-being. Combining these strategies with a process of iterative monitoring, evaluation, learning, innovation, and contingency planning will reduce climate change disaster risks, promote adaptive management, and contribute significantly to prospects for climate-resilient pathways.

inadequate efforts to address effects of emerging climate stressors are already eroding the basis for sustainable development. New studies find that among people who attempt to cope with current stresses, most experienced negative residual impacts and as a consequence faced eroding household income and food security, health, and education opportunities and were more likely to migrate and lose housing and livelihood assets (Monnereau and Abraham, 2013; Rabbani et al., 2013; Traore et al., 2013; Warner and van der Geest, 2013; Yaffa, 2013). For example, in the Punakha district in Bhutan, 87% of households that adopted coping measures reported that they were still experiencing adverse effects of changing monsoon patterns despite the adaptation measures (Kusters and Wangdi, 2013). Evidence (Chapters 7, 8, 12, 13, 16, 19) suggests that waiting to take more effective action may reduce the range of choices for climate-resilient pathways in the future (National Research Council, 2011).

More generally, IPCC (2012) makes the case that a window of opportunity exists now for considering possible strategies that would increase climate resilience while at the same time helping to improve human livelihoods and social and economic well-being. It suggests that a process of iterative monitoring, evaluation, learning, innovation, and contingency planning will reduce climate change disaster risks, promote adaptive management, and contribute significantly to prospects for climate-resilient pathways. In this sense, strategies and actions can be pursued now that will move toward climate-resilient pathways while at the same time helping to improve human livelihoods, social and economic well-being, and responsible environmental management.

As policy makers explore what pathways to pursue, they will increasingly face questions about managing discourses about what societal objectives to pursue unchanged, where compromises in objectives are tolerable, and what consequences including loss and damage may be associated with different pathways. In considering possible needs for transformational pathways (Section 20.5), extreme weather occurrences such as major floods, wildfires, cyclones, and heat waves may focus societal attention on vulnerabilities and stressors and provide a "policy window" for major changes (Kingdon, 1995; Birkland, 2006; Kates et al., 2012). Discussions of transformation may require broader-based social discourse (Pelling et al., 2007) and iterative institutional learning (Berkhout et al., 2006), on the basis of growing evidence, knowledge, and experience. Systems to monitor emerging stresses and threats will aid decision makers at different scales to evaluate alternative pathways (Kates et al., 2012).

20.7. Priority Research/Knowledge Gaps

Because integrating climate change mitigation, climate change adaptation, and sustainable development is a relatively new challenge, research should be a very high priority indeed to inform strategies and actions. The most salient research need is to improve the understanding of how climate change mitigation and adaptation can be combined with resilient sustainable development pathways in a wide variety of regional and sectoral contexts (Wilbanks, 2010). One starting point is simply improving the capacity to characterize benefits, costs, potentials, and limitations of major mitigation and adaptation options, along with their external implications for equitable development, so that integrated climate change response strategies can be evaluated more carefully (Wilbanks et al., 2007; National Research Council, 2011). What are the major trade-offs? What are the potential synergies? How do implications of integrated mitigation/adaptation strategies vary with location, climate change risks and vulnerabilities, scale, and development objectives and capacities (e.g., Hugé et al., 2011)? In these regards, the best of global science needs to be combined with national and local expertise to advance knowledge related to climate-resilient pathways.

Related to this general priority are at least three specific research needs:

- Advances in conceptual and methodological understandings of, and tools to support research on, multiple drivers of development pathways and climate change impacts; possible feedback effects among mitigation, adaptation, and development; possible thresholds/tipping points that could cause particular challenges for development; and possible transformations to reduce losses and damages and support sustainable development (Stern and Wilbanks, 1999; National Research Council, 2010a; see also Section 20.5).
- Advances in knowledge about how to respond sustainably to climate change extremes and extreme events, when and where they pose development challenges that would appear to require transformative changes in affected human and/or environmental systems. What might the response options be, and how can they be facilitated where they merit consideration (e.g., Pelling, 2010; Lemos et al., 2013)?
- Research on how to reconcile the importance of synergies between climate change adaptation and mitigation actions with widespread use of the concept of "additionality." For example, how might criteria be established for access to financial support for adaptation that incorporates the development importance of co-benefits? Such research could inform discourses about differences between adaptation and development in ways that enable the flow of financial resources to support adaptations (National Research Council, 2010a).

Further research needs include:

- Research attention to potentials for technological and institutional innovations to ease threats to sustainable development from climate change impacts and responses. In other words, how might climate change responses represent opportunities for innovative development paths? How might technological development be part of a strategy for development/climate change response integration (Wilbanks, 2010)?
- Research on strategies for institutional development, including improving understanding of how social institutions affect resource use (Stern and Wilbanks, 1999), improving understanding of risk-related judgment and decision-making under uncertainty (Stern and Wilbanks, 1999), and best practices in creating institutions that will effectively integrate climate change responses with sustainable development characteristics such as participation, equity, and accountability.
- Research on strategies for the implementation of adaptive management and risk reduction for development. Examples of important research needs include improving the understanding of respective roles and interactions between autonomous response behavior and policy initiatives; improving the body of empirical evidence about how to implement changes that are judged to be desirable, for example, adaptive management and governance capacity; and improving the understanding of differences between

retrofitting older infrastructures (challenge in many industrialized countries) and designing new infrastructures (challenge in many rapidly developing countries) (IPCC, 2012, Chapter 8).

- Research to improve the understanding of how to build social inclusiveness into development/climate change response integration. As suggested above, research is needed on issues of social values/climate justice/equity/participation and how they intersect with the deployment of mitigation, adaptation interventions, and sustainable development policy in different regional/sociopolitical contexts (IPCC, 2012, Chapter 8).
- Research on factors that influence deliberate transformations that are ethical, equitable, and sustainable (Kates et al., 2012; O'Brien, 2012).
- The development of structures for learning from emerging integrated climate change response/development experience, for example, approaches and structures for monitoring, recording, evaluating, and learning from experience and identifying "best practices" and their characteristics (National Research Council, 2010a; Hilden, 2011; IPCC, 2012, Chapter 8).

Finally, it is very possible that progress with global climate change mitigation will not be sufficient to avoid relatively high levels of regional and sectoral impacts, and that such conditions would pose growing challenges to the capacity of adaptation to avoid serious disruptions to development processes. If this were to become a reality later in this century, one response could be a rush toward geoengineering approaches. In preparation for such a contingency, and perhaps as an additional way to show how important progress with mitigation will be in framing prospects for sustainable development in many contexts, there is a very serious need for research on geoengineering costs, benefits, risks, a wide range of possible impacts, and fair and equitable structures for global policy and decision making (UK Royal Society, 2009; Kates et al., 2012).

But a fundamental aim of research to improve capacities for climate-resilient pathways for sustainable development is to avoid such an unfortunate outcome. It seeks to do so by strengthening the base of knowledge that underlies and supports effective actions by viewing climate change mitigation, climate change adaptation, and sustainable development in an integrative and mutually supportive way.

References

ADB and ADBI, 2012: *Low-Carbon Green Growth in Asia: Policies and Practices.* Joint study of the Asian Development Bank (ADB) and the Asian Development Bank Institute (ADBI), ADB, Manila, Philippines, 246 pp.

Adger, W.N., 2010: Climate change, human well-being, and insecurity. *New Political Economy*, **15(2)**, 275-292.

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**, 179-195.

Adger, W.N., K. Brown, D.R. Nelson, F. Berkes, H. Eakin, C. Folke, K. Galvin, L. Gunderson, M. Goulden, and K. O'Brien, 2011: Resilience implications of policy responses to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, **2(5)**, 757-766.

Agrawal, A., 2010: Local institutions and adaptation to climate change. In: *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World* [Mearns, R. and A. Norton (eds.)]. The International Bank for Reconstruction and Development / The World Bank, Washington, DC, USA, pp. 173-198.

Agrawal, A., R. Mearns, N. Perrin, and M. Kononen, 2011: *Area-Based Development, Local Institutions & Climate Adaptation: A Comparative Analysis from West Africa and Latin America.* The World Bank Group, Washington, DC, USA, 56 pp.

Agrawala, S. and M. van Aalst, 2008: Adapting development cooperation to adapt to climate change. *Climate Policy*, **8(2)**, 183-193.

Anderson, K. and A. Bows, 2008: Reframing the climate change challenge in light of post-2000 emission trends. *Philosophical Transactions of the Royal Society A*, **366(1882)**, 3863-3882.

Angelson, A., 2009: *Realizing REDD+: National Strategy and Policy Options.* Center for International Forestry Research (CIFOR), Bogor, Indonesia, 362 pp.

Arndt, C., P. Chinowsky, S. Robinson, K. Strzepek, R. Tarp, and R. Thurlow, 2012: Economic development under climate change. *Review of Development Economics*, **16(3)**, 369-377, doi: 10.1111/j.1467-9361.2012.00668.x.

Arnell, N.W., J.A. Lowe, S. Brown, S.N. Gosling, P. Gottschaalk, J. Hinkel, B. Lloyd-Hughes, R.J. Nicholls, T.J. Osborn, T.M. Osborne, G.A. Rose, P. Smith, and R.F. Warren, 2013: A global assessment of the effects of climate policy on the impacts of climate change. *Nature Climate Change*, **3**, 512-519.

Auerswald, H., K. Konrad, and M.P. Thum, 2011: *Adaptation, Mitigation and Risk-Taking in Climate Policy.* CESifo Working Paper No. 3320, Category 10: Energy and Climate Economics, The CESifo Group: the Center for Economic Studies (CES), the Ifo Institute and the Munich Society for the Promotion of Economic Research (CESifo GmbH), The CESifo Group, Munich, Germany, 22 pp.

Ayers, J.M. and S. Huq, 2009: The value of linking mitigation and adaptation: a case study of Bangladesh. *Environmental Management*, **43(5)**, 753-764.

Bäckstrand, K., 2003: Civic science for sustainability: reframing the role of experts, policy-makers and citizens in environmental governance. *Global Environmental Politics*, **3(4)**, 24-41.

Bamuri, T. and M.H. Opeschoor, 2007: Climate change and sustainable development: realizing the opportunity. *Ambio*, **35(1)**, 2-8.

Banerjee, S.B., 2012: A climate for change? Critical reflections on the Durban United Nations Climate Change Conference. *Organization Studies*, **33(12)**, 1761-1786, doi:10.1177/0170840612464609.

Barker, T., 2008: The economics of avoiding dangerous climate change. An editorial essay on The Stern Review. *Climatic Change*, **89(3-4)**, 173-194.

Baumol, W. and W. Oates, 1989: *The Theory of Environmental Policy.* Cambridge University Press, Cambridge, UK, 299 pp.

Beckman, M., 2011: Converging and conflicting interests in adaptation to environmental change in central Vietnam. *Climate and Development*, **3**, 32-41.

Beddoe, R., R. Costanza, J. Farley, E. Garza, J. Kent, I. Kubiszewski, L. Martinez, T. McCowen, K. Murphy, N. Myers, Z. Ogden, K. Stapleton, and J. Woodward, 2009: Overcoming systemic roadblocks to sustainability: the evolutionary redesign of worldviews, institutions, and technologies. *Proceedings of the National Academy of Sciences of the United States of America*, **106(8)**, 2483-2489.

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

Bell, A., N. Engle, and M. Lemos, 2011: How does diversity matter? The case of Brazilian river basin councils. *Ecology and Society*, **16(1)**, 42, www.ecologyandsociety.org/vol16/iss1/art42/.

Benn, S., D. Dunphy, and A. Martin, 2009: Governance of environmental risk: new approaches to managing stakeholder involvement, *Journal of Environmental Management*, **90**, 1567-1575.

Berkes, F., 2007: Understanding uncertainty and reducing vulnerability: lessons from resilience thinking. *Natural Hazards*, **41**, 283-295.

Berkhout, F., J. Hertin, and D.M. Gann, 2006: Learning to adapt: organizational adaptation to climate change impacts. *Climatic Change*, **78**, 135-156.

Berkhout, F., G. Verbong, A.J. Wieczorek, R. Raven, L. Lebel, and X. Bai, 2010: Sustainability experiments in Asia: innovations shaping alternative development pathways? *Environmental Science and Policy*, **13**, 261-271.

Bierbaum, R., J.B. Smith, A. Lee, M. Blair, L. Carter, F.S. Chapin, P. Fleming, S. Ruffo, M. Stultz, S. McNeeley, E. Wasley, and L. Verduzzo, 2013: A comprehensive review of climate adaptation in the United States: more than before, but less than needed. *Mitigation and Adaptation Strategies for Global Change*, **18(3)**, 361-406.

Biesbroek, G.R., J. Swart, and W.G.M. van der Knaap, 2009: The mitigation-adaptation dichotomy and the role of spatial planning. *Habitat International*, **33(3)**, 230-237.

Birkland, T.A., 2006: *Lessons of Disaster: Policy Change After Catastrophic Events.* Georgetown University Press, Washington, DC, USA, 216 pp.
Bisaro, A., J. Hinkel, and N. Kranz, 2010: Multilevel water, biodiversity, and climate adaptation governance: evaluating adaptive management in Lesotho. *Environmental Science & Policy*, **13**, 637-647.
Bizikova, L., J. Robinson, and S. Cohen, 2007: Linking climate change and sustainable development at the local level. *Climate Policy*, **7**, 271-277.
Bizikova, L., T. Neale, and I. Burton, 2008: *Canadian Communities' Guidebook for Adaptation to Climate Change. Including an Approach to Generate Mitigation Co-Benefits in the Context of Sustainable Development.* 1st edn, Adaptation and Impacts Research Division (AIRD), Environment Canada and the University of British Columbia, Vancouver, Environment Canada, Toronto, ON, Canada, 100 pp.
Bizikova, L., S. Burch, S. Cohen, and J. Robinson, 2010: Linking sustainable development with climate change adaptation and mitigation. In: *Climate Change, Ethics and Human Security* [O'Brien, K., A. St. Clair, and B. Kristoffersen (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 157-179.
Blackstock, J.J. and J.C.S. Long, 2010: The politics of geoengineering. *Science*, **327(5965)**, 527, doi:10.1126/science.1183877.
Boyd, E., H. Osbahr, P.J. Ericksen, E.L. Tompkins, M.C. Lemos, and F. Miller, 2008: Resilience and climatizing development: examples and policy implications. *Development*, **51(3)**, 390-396.
Brooks, N., W.N. Adger, and P.M. Kelley, 2005: The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change: Human and Policy Dimensions*, **15(2)**, 151-163.
Brovkin, V., V. Petoukhov, M. Claussen, E. Bauer, A. Archer, and C. Jaeger, 2009: Geoengineering climate by stratospheric sulfur injections: Earth system vulnerability to technological failure. *Climatic Change*, **92**, 243-259.
Brown, K., 2011: Sustainable adaptation: an oxymoron? *Climate and Development*, **3**, 21-31.
Brown, L., 1981: *Building a Sustainable Society.* W.W. Norton & Co. Inc., New York, NY, USA, 433 pp.
Bryan, E., C. Ringler, B. Okoba, J. Koo, M. Herrero, and S. Silvestri, 2013: Can agriculture support climate change adaptation, greenhouse gas mitigation and rural livelihoods? Insights from Kenya. *Climatic Change*, **118(2)**, 151-165.
Bulkeley, H. and H. Schroeder, 2012: Beyond state/non-state divides: global cities and the governing of climate change. *European Journal of International Relations*, **18(4)**, 743-766.
Burch, S., 2010: Transforming barriers into enablers of action on climate change: insights from three municipal case studies in British Columbia, Canada. *Global Environmental Change: Human and Policy Dimensions*, **20**, 287-297.
Burton, I., S. Huq, B. Lim, O. Pilifosova, and E.L. Schipper, 2002: From impact assessment to adaptation priorities: the shaping of adaptation policy. *Climate Policy*, **2**, 145-159.
Cafaro, P., 2010: Getting to less. *Ethics, Place, and Environment*, **13(1)**, 11-14.
Calvin, K., J. Edmonds, B. Bond-Lamberty, L. Clarke, S.H. Kim, P. Kyle, S.J. Smith, A. Thomson, and M. Wise, 2009: 2.6: Limiting climate change to 450 ppm CO_2 equivalent in the 21st century. *Energy Economics,* **31(Suppl. 2)**, S107-S120.
Campbell-Lendrum, D. and R. Woodruff, 2006: Comparative risk assessment of the burden of disease from climate change. *Environmental Health Perspectives*, **114**, 1935-1941.
Chhatre, A. and A. Agrawal, 2009: Trade-offs and synergies between carbon storage and livelihood benefits from forest commons. *Proceedings of the National Academy of Sciences of the United States of America*, **108(42)**, 17667-17670.
Chuku, C.A., 2009: Pursuing an integrated development and climate policy framework in Africa: options for mainstreaming. *Mitigation and Adaptation Strategies for Global Change*, **15(1)**, 41-52.
Chukwumerije, O. and H. Schroeder, 2009: How can justice, development and climate mitigation be reconciled for developing countries in a post-Kyoto settlement? *Climate and Development*, **1**, 10-15.
Clark, A.E., P. Frijters, and M.A. Shields, 2008: Relative income, happiness, and utility: an explanation for the Easterlin Paradox and other puzzles. *Journal of Economic Literature*, **46(1)**, 95-144.
Corbera, E. and K. Brown, 2008: Building institutions to trade ecosystem services: marketing forest carbon in Mexico. *World Development*, **36**, 1956-1979.
Crutzen, P.J., 2006: Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma? *Climatic Change*, **77(3-4)**, 211-220.
Crutzen, P.J. and E.F. Stoermer, 2000: The "Anthropocene". *Global Change Newsletter*, **41**, 17-18.
Dang, H.H., A. Michaelowa, and D.D. Tuan, 2003: Synergy of adaptation and mitigation strategies in the context of sustainable development: the case of Vietnam. *Climate Policy*, **3(Suppl. 1)**, S81-S96.
De Boer, J., J.A. Wardekker, and J.P. van der Sluijs, 2010: Frame-based guide to situated decision-making on climate change. *Global Environmental Change: Human and Policy Dimensions*, **20(3)**, 502-510.
Deaton, A., 2008: Income, health and well-being around the world: evidence from the Gallup World Poll. *Journal of Economic Perspectives*, **22**, 53-72.
Deere-Birbeck, C., 2009: Global governance in the context of climate change: the challenges of increasingly complex risk parameters. *International Affairs*, **85(6)**, 1173-1194.
DeLeire, T. and A. Kalil, 2010: Does consumption buy happiness? Evidence from the United States. *International Review of Economics*, **57(2)**, 163-176.
Dickinson, T. (ed.), 2007: *Compendium of Adaptation Models for Climate Change.* 1st edn., Adaptation and Impacts Research Division (AIRD), Environment Canada, Toronto, ON, Canada, 41 pp.
Dolan, P. and M.P. White, 2007: How can measures of subjective well-being be used to inform public policy? *Perspectives in Psychological Science*, **2**, 71-85.
Dovers, S.R. and A.A. Hezri, 2010: Institutions and policy processes: the means to the ends of adaptation. *Wiley Interdisciplinary Reviews: Climate Change*, **1(2)**, 212-231.
Drouineau, H., J. Lobry, C. Delpech, M. Bouchoucha, S. Mahevas, A. Courrat, S. Pasquaud, and M. Lepage, 2012: A Bayesian framework to objectively combine metrics when developing stressor specific multimetric indicators. *Ecological Indicators*, **13**, 314-321.
Eakin, H., 2005: Institutional change, climate risk, and rural vulnerability: cases from central Mexico. *World Development*, **33**, 1923-1938.
Eakin, H. and M.C. Lemos, 2006: Adaptation and the state: Latin America and the challenge of capacity-building under globalization. *Environmental Change-Human and Policy Dimensions*, **16**, 7-18.
Easterlin, R.A., 1974: Does economic growth improve the human lot? In: *Nations and Households in Economic Growth: Essays in Honor of Moses Abramovitz* [David, P.A. and M.W. Reder (eds.)]. Academic Press, Inc., New York, NY, USA, pp. 89-125.
Easterlin, R.A., 2001: Income and happiness: toward a unified theory. *Economic Journal*, **111**, 465-484.
Edenhofer, O., J. Wallacher, H. Lotze-Campen, M. Reder, B. Knopf, and J. Müller, 2012: *Climate Change, Justice and Sustainability: Linking Climate and Development Policy.* Springer, Dordrecht, Netherlands, 401 pp.
Editorial Board of National Climate Change Assessment, 2011: *Second National Climate Change Assessment Report.* Editorial Board of National Climate Change Assessment (EBNCCA), Science Press, Beijing, China, 710 pp.
Ehrenfeld, J., 2008: *Sustainability by Design: A Subversive Strategy for Transforming Our Consumer Culture.* Yale University Press, New Haven, CT, USA, 246 pp.
Engle, N.L., 2013: The role of drought preparedness in building and mobilizing adaptive capacity in states and their community water systems. *Climatic Change*, **118(2)**, 291-306.
EPA, 2012: *Co-Benefits Risk Assessment (COBRA) Screening Model: A Tool that Estimates the Health and Economic Benefits of Air Quality Policies.* U.S. Environmental Protection Agency (EPA), Washington, DC, USA, epa.gov/statelocalclimate/resources/cobra.html.
Eriksen, S. and K. Brown, 2011: Sustainable adaptation to climate change. *Climate and Development*, **3(1)**, 3-6.
Eriksen, S., P. Aldunce, C.S. Bahinipati, R.D. Martins, J.I. Molefe, C. Nhemachena, K. O'Brien, F. Olorunfemi, J. Park, L. Sygna, and K. Ulsrud, 2011: When not every response to climate change is a good one: identifying principles for sustainable adaptation. *Climate and Development*, **3(1)**, 7-20, doi:10.3763/cdev.2010.0060.
Falloon, P. and R. Betts, 2010: Climate impacts on European agriculture and water management in the context of adaptation and mitigation – the importance of an integrated approach. *Science of the Total Environment*, **408(23)**, 5667-5687.
FDRE, 2011: *Ethiopia's Climate-Resilient Green Economy: Green Economy Strategy.* Federal Democratic Republic of Ethiopia (FDRE), Addis Ababa, Ethiopia, 188 pp.
Fleurbaey, M., 2009: Beyond GDP: the quest for a measure of well-being and social welfare. *Journal of Economic Literature*, **47**, 1029-1075.
Folke, C., 2006: Resilience: the emergence of a perspective for social-ecological systems analyses. *Global Environmental Change*, **16(3)**, 253-267.
Folke, C., S.R. Carpenter, T. Elmqvist, L. Gunderson, C.S. Holling, and B. Walker, 2002: Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio*, **31**, 437-440.

Folke, C., S.R. Carpenter, B. Walker, M. Scheffer, T. Chapin, and J. Rockström, 2010: Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society*, **15(4)**, 20, www.ecologyandsociety.org/vol15/iss4/art20/.
Forsyth, T., 2007: Promoting the "development dividend" of climate technology transfer: can cross-sector partnerships help? *World Development*, **35**, 1684-1698.
Frey, G.W. and D.J. Linke, 2002: Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. *Energy Policy*, **30**, 1261-1265.
Gao, Q.-z., Y.-f. Wan, H.-m. Xu, Y. Li, W.-z. Jiangcun, and A. Borjigidai, 2010: Alpine grassland degradation index and its response to recent climate variability in Northern Tibet, China. *Quaternary International*, **226(1-2)**, 143-150.
Gao, Q.-z., Y. Li, H.-m. Xu, Y.-f. Wan, and W.-z. Jiangcun, 2012: Adaptation strategies of climate variability impacts on alpine grassland ecosystems in Tibetan Plateau. *Mitigation and Adaptation Strategies for Global Change*, **19(2)**, 199-209.
Gardiner, S., 2010: Ethics and climate change: an introduction. *Wiley Interdisciplinary Reviews: Climate Change*, **1(1)**, 54-56.
Gardiner, S.M., S. Caney, D. Jamieson, and H. Shue, 2010: *Climate Ethics: Essential Readings.* Oxford University Press, New York, NY, USA, 351 pp.
Garg, A., P.R. Shukla, and M. Kapshe, 2007: From climate change impacts to adaptation: a development perspective for India. *Natural Resources Forum*, **31**, 132-141.
Garg, A., R. Dahiman, S. Bhattacharya, and P.R. Shukla, 2009: Development, malaria and adaptation to climate change: a case study from India. *Environmental Management*, **43**, 779-789.
Geels, F.W., 2002: Technological transitions as evolutionary reconfiguration processes: a multilevel perspective and case study. *Research Policy*, **31(8-9)**, 1257-1274.
Goes, M., N. Tuana, and K. Keller, 2011: The economics (or lack thereof) of aerosol geoengineering. *Climatic Change*, **109**, 719-744.
Grist, N., 2008: Positioning climate change in sustainable development discourse. *Journal of International Development*, **20**, 783-803.
Gulledge, J., L.J. Richardson, L. Adkins, and S. Seidel (eds.), 2010: *Assessing the Benefits of Avoided Climate Change: Cost-Benefit Analysis and Beyond*. Proceedings of Workshop on Assessing the Benefits of Avoided Climate Change, Washington, DC, March 16-17, 2009, Pew Center on Global Climate Change: Arlington, VA, USA, 231 pp.
Gupta, J., K. Termeer, J. Klostermann, S. Meirjerirnk, M. van den Brink, P. Jong, and S. Nooteboom, 2008: *Institutions for Climate Change: A Method to Assess the Inherent Characteristics of Institutions to Enable the Adaptive Capacity of Society.* Institute for Environmental Studies, Amsterdam, Netherlands, 19 pp.
Gupta, J., C. Termeer, K. Klostermann, S. Meijerink, M. van den Brink, P. Jong, S. Nooteboom, and E. Bergsma, 2010: The adaptive capacity wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science & Policy*, **13**, 459-471.
Hallegatte, S., 2009: Strategies to adapt to an uncertain climate change. *Global Environmental Change*, **19(2)**, 240-247.
Halsnaes, K. and J. Verhagen, 2007: Development based climate change adaptation and mitigation. Conceptual issues and lessons learned in studies in developing countries. *Mitigation and Adaptation Strategies for Global Change*, **12(5)**, 665-684.
Halsnaes, K., P.R. Shukla, and A. Garg, 2008: Sustainability development and climate change: lessons from country studies. *Climate Policy*, **8(2)**, 202-219.
Hamin, E.M. and N. Gurran, 2009: Urban form and climate change: balancing adaptation and mitigation in the US and Australia. *Habitat International*, **33**, 238-245.
Handmer, J. and S. Dovers, 1996: A typology of resilience: rethinking institutions for sustainable development. *Industrial and Environmental Crisis Quarterly*, **9(4)**, 482-511, doi: 10.1177/108602669600900403.
Hanjra, M.A. and M.E. Qureshi, 2010: Global water crisis and future food security in an era of climate change. *Food Policy*, **35**, 365-377.
Hardee, K. and C. Mutunga, 2009: Strengthening the link between climate change adaptation and national development plans: lessons from the case of population in National Adaptation Programmes of Action (NAPAs). *Mitigation and Adaptation Strategies for Global Change*, **15(2)**, 113-126.
Hazell, P., J. Anderson, N. Balzer, A. Hastrup-Clemmensen, U. Hess, F. Rispoli, K. Hardee, and C. Mutunga, 2010: *The Potential for Scale and Sustainability in Weather Index Insurance for Agriculture and Rural Livelihoods*. International Fund for Agricultural Development (IFAD) and World Food Programme (WFP) working jointly through the IFAD-WFP Weather Risk Management Facility (WRMF), Rome, Italy, 153 pp.
Heifetz, R., A. Grashow, and M. Linsky, 2009: *The Practice of Adaptive Leadership: Tools and Tactics for Changing Your Organization and the World.* Harvard Business School, Cambridge, MA, USA, 326 pp.
Heltberg, R., P.B. Siegel, and S.L. Jorgensen, 2009: Addressing human vulnerability to climate change: toward a no-regrets approach. *Global Environmental Change*, **19(1)**, 89-99.
Hernes, G., 2012: *Hot Topic – Cold Comfort: Climate Change and Attitude Change.* Nordem Top Research Initiative, Oslo, Norway, 158 pp.
Hilden, M., 2011: The evolution of climate policies: the role of learning and evaluations. *Journal of Cleaner Production*, **19**, 1798-1811.
Hodgson, G.M., 2003: The hidden persuaders: institutions and individuals in economic theory. *Cambridge Journal of Economics*, **27(2)**, 159-175.
Hof, A.F., K.C. de Bruin, R.B. Dellink, M.G.J. den Elzen, and D.P. van Vuuren, 2009: The effect of different mitigation strategies on international financing of adaptation. *Environmental Science & Policy*, **12**, 832-843.
Holling, C.S., 1973: Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, **4**, 1-23.
Huesemann, M.H., 2006: Can advances in science and technology prevent global warming? A critical review of limitations and challenges. *Mitigation and Adaptation Strategies for Global Change*, **11(3)**, 539-577.
Hueting, R., 2010: Why environmental sustainability can most probably not be attained with growing production. *Journal of Cleaner Production*, **18(6)**, 525-530.
Hugé, J., T. Waas, G. Eggermont, and A. Verbruggen, 2011: Impact assessment for a sustainable energy future: reflections and practical experiences. *Energy Policy*, **39**, 6243-6253.
International Council for Science, 2002: *Science and Technology for Sustainable Development: Consensus Report and Background Document, Mexico City Synthesis Conference, 20-23 May 2002*. ICSU Series on Science for Sustainable Development No. 9, International Council for Science (ICSU), Paris, France, 30 pp.
IPCC, 2007a: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 976 pp.
IPCC, 2007b: Summary for policymakers. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, (eds.)]. Cambridge University Press, UK and New York, NY, USA, pp. 7-22.
IPCC, 2011: *Special Report on Renewable Energy Sources and Climate Change Mitigation.* Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 1075 pp.
IPCC, 2012: *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 582 pp.
Jerneck, A. and L. Olsson, 2008: Adaptation and the poor: development, resilience and transition. *Climate Policy*, **8**, 170-182.
Johnston, R., K. Segerson, E.T. Schultz, E.Y. Besedin, and M. Ramachandran, 2011: Indices of biotic integrity in stated preference valuation of ecosystem services. *Ecological Economics*, **70(11)**, 1946-1956.
Juma, C., 2011: *The New Harvest: Agricultural Innovation in Africa.* Oxford University Press, New York, NY, USA, 270 pp.
Kates, R.W., 2000a: Cautionary tales: adaptation and the global poor. *Climatic Change*, **45**, 5-17.
Kates, R.W., 2000b: Population and consumption: what we know, what we need to know. *Environment*, **42(3)**, 10-19.
Kates, R.W., W.N. Travis, and T.J. Wilbanks, 2012: Transformational adaptation when incremental adaptations are insufficient. *Proceedings of the National Academy of Sciences of the United States of America*, **109(19)**, 7156-7161.
Keith, D.W., 2000: Geoengineering the climate: history and prospect. *Annual Review, Energy and Environment*, **25**, 245-284.
Kemp, R., 1994: Technology and the transition to environmental sustainability: the problems of technological regime shifts. *Futures*, **26(10)**, 1023-1046.

Kingdon, J.W., 1995: *Agendas, Alternatives, and Public Policies*. 2nd edn., Addison-Wesley Educational Publishers, Inc., New York, NY, USA, 253 pp.

Klein, R., E. Schipper, and S. Dessai, 2005: Integrating mitigation and adaptation into climate and development policy: three research questions. *Environmental Science and Policy*, **8(6)**, 579-588.

Klenow, P.J. and A. Rodríguez-Clare, 2005: Externalities and growth. In: *Handbook of Economic Growth* [Aghion, A.P. and S. Durlauf (eds.)]. Vol. 1A, Elsevier B.V., Amsterdam, Netherlands, pp. 817-861.

Kok, M., B. Metz, J. Verhagen, and S. Van Rooijen, 2008: Integrating development and climate policies: national and international benefits. *Climate Policy*, **8(2)**, 103-118.

Kopytko, N. and J. Perkins, 2011: Climate change, nuclear power, and the adaptation-mitigation dilemma. *Energy Policy*, **39**, 318-333.

Kriegler, E., B.C. O'Neill, S. Hallegate, T. Kram, R.J. Lempert, R.H. Moss, and T.J. Wilbanks, 2012: The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. *Global Environmental Change*, **22(4)**, 807-822.

Kristjanson, P., R.S. Reid, N. Dickson, W.C. Clark, D. Romney, R. Puskur, S. MacMillan, and D. Grace, 2009: Linking international agricultural research knowledge with action for sustainable development. *Proceedings of the National Academy of Sciences of the United States of America*, **106(13)**, 5047-5052.

Kusters, K. and N. Wangdi, 2013: The costs of adaptation: changes in water availability and farmers' responses in Punakha district, Bhutan. *International Journal of Global Warming*, **5(4)**, 387-399.

La Rovere, E.L., A.C. Avzaradel, and J.M.G. Monteiro, 2009: Potential synergy between adaptation and mitigation strategies: production of vegetable oils and biodiesel in northeastern Brazil. *Climate Research*, **40**, 233-239.

Lafferty, W.M. and J. Meadowcroft, 2010: *Implementing Sustainable Development: Strategies and Initiatives in High Consumption Societies.* Oxford University Press, New York, NY, USA, 523 pp.

Lebel, L., 2005: Carbon and water management in urbanization. *Global Environmental Change*, **15(4)**, 293-295.

Leiserowitz, A.A., R.W. Kates, and T.M. Parris, 2005: What is sustainable development? Goals, indicators, values, and practice. *Environment: Science and Policy for Sustainable Development*, **47(1)**, 8-21.

Lemos, M.C., A. Agrawal, O. Johns, D. Nelson, and N. Engle, 2013: Building adaptive capacity to climate change in less developed countries. In: *Climate Science for Serving Society: Research, Modeling and Prediction Priorities* [Asrar, G.R. and J.W. Hurrell (eds.)]. OSC Monograph Reviews, Springer Science, Dordrecht, Netherlands, pp. 437-458.

Lenton, T.M., 2011a: Early warning of climate tipping points. *Nature Climate Change*, **1**, 201-209.

Lenton, T.M., 2011b: 2 °C or not 2 °C? That is the climate question. *Nature*, **473**, 7, doi:10.1038/473007a.

Locatelli, B., V. Evans, A. Wardell, A. Andrade, and R. Vignola, 2011: Forests and climate change in Latin America: linking adaptation and mitigation in projects and policies. *Forests*, **2**, 431-450.

Loorbach, D., 2007: Governance for sustainability. *Sustainability: Science, Practice & Policy*, **3(2)**, 1-4.

Lovins, L.H. and B. Cohen, 2011: *Climate Capitalism: Capitalism in the Age of Climate Change.* Hill and Wang, New York, NY, USA, 272 pp.

MacCracken, M., 2011: Potential applications of climate engineering technologies to moderation of critical climate change impacts. In: *Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Geoengineering* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, C. Field, V. Barros, T.F. Stocker, Q. Dahe, J. Minx, K. Mach, G.-K. Plattner, S. Schlömer, G. Hansen, and M. Mastrandrea (eds.)]. Meeting held in Lima, Peru, 20-22 June 2011, IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam, Germany, pp. 55-56.

Malthus, T.R., 1798: *An Essay on the Principle of Population, as it Affects the Future Improvement of Society, with Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers*. 1st edn., J. Johnson, London, UK, 396 pp.

Manyena, S.B., 2006: The concept of resilience revisited. *Disasters*, **30(4)**, 433-450.

Marshall, N.A., S.E. Park, W.N. Adger, K. Brown, and S.M. Howden, 2012: Transformational capacity and the influence of place and identity. *Environmental Research Letters*, **7(3)**, 034022, doi:10.1088/1748-9326/7/3/034022.

Marston, A., 2012: *One Planet – One Future: Equity and Resilience for Sustainable Development: CARE at Rio Plus 20*. CARE Denmark (CARE DK), Kobenhavn, Denmark, 27 pp.

Matthew, R.A. and A. Hammill, 2009: Sustainable development and climate change *International Affairs*, **85(6)**, 1117-1128.

McSweeney, K. and O.T. Coomes, 2011: Climate-related disaster opens a window of opportunity for rural poor in northeastern Honduras. *Proceedings of the National Academy of Sciences of the United States of America*, **108(13)**, 5203-5208.

Meadowcroft, J., 2000: Sustainable development: a new(ish) idea for a new century? *Political Studies*, **48(2)**, 370-387.

Meadowcroft, J., 2009: What about the politics? Sustainable development, transition management, and long term energy transitions. *Policy Sciences*, **42(4)**, 323-340.

Metz, B. and M. Kok, 2008: Integrating development and climate policies. *Climate Policy*, **8**, 99-102.

Metz, B., M. Berk, M. den Elzen, B. de Vries, and D. van Vuuren, 2002: Towards an equitable global climate change regime: a compatibility with Article 2 of the Climate Change Convention and the link with sustainable development. *Climate Policy*, **2(2-3)**, 211-230.

Millar, C.I., N.L. Stephenson, and S.L. Stephens, 2007: Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications*, **17(8)**, 2145-2151.

Miller, A.S., 2008: Financing the integration of climate change mitigation into development. *Climate Policy*, **2**, 152-169.

Mirza, M.M.Q., 2003: Climate change and extreme weather events: can developing countries adapt? *Climate Policy*, **3**, 233-248.

Mitchell, T., and S. Dovers, 2006: *Adapting to Climate Change: Challenges and Opportunities for the Development Community.* Institute of Development Studies (IDS), Tearfund, Teddington, UK, 36 pp.

Mitchell, T. and T. Tanner, 2006: *Overcoming the Barriers: Mainstreaming Climate Adaptation in Developing Countries.* Tearfund Climate Change Briefing Paper 1, Climate Change and Disasters Group, Institute of Development Studies (IDS), Tearfund, Teddington, UK, 28 pp.

Moed, H. and A. Plume, 2011: The multi-dimensional research assessment matrix. *Research Trends*, **(23)**, 5-7.

Monnereau, I. and S. Abraham, 2013: Limits to autonomous adaptation in response to coastal erosion in Kosrae, Micronesia. *International Journal of Global Warming*, **5(4)**, 416-432.

Morgan, J. and T. Farsides, 2009: Measuring meaning in life. *Journal of Happiness Studies*, **10**, 197-214.

Muller, B., 2009: *Additionality in the Clean Development Mechanism: Why and What?* Oxford Institute for Energy Studies, EV44, Oxford, UK, 18 pp.

Munasinghe, M., 2010: Addressing the sustainable development and climate change challenges together: applying the sustainonomics framework. *Procedia – Social and Behavioral Sciences*, **2(5)**, 6634-6640.

Naess, L.O., G. Bang, S. Eriksen, and J. Vevatne, 2005: Institutional adaptation to climate change: flood responses at the municipal level in Norway. *Global Environmental Change: Human and Policy Dimensions*, **15(2)**, 125-138.

Nelson, D.R., N. Adger, and K. Brown, 2007: Adaptation to environmental change: contributions of a resilience framework. *Annual Review of Environment and Resources*, **32(1)**, 395-419.

Nelson, R.R. and S. Winter, 1982: *An Evolutional Theory of Economic Change.* Harvard University Press, Cambridge, MA, USA, 437 pp.

Ness, B., E. Urbel-Pirsalu, S. Anderberg, and S. Olsson, 2007: Categorising tools for sustainability assessment. *Ecological Economics*, **60**, 498-508.

Netherlands Environmental Assessment Agency, 2009: *Co-Benefits of Climate Policy.* Netherlands Environmental Assessment Agency (PBL), Bilthoven, Netherlands, 72 pp.

New, M., D. Liverman, H. Schroder, and K. Anderson, 2012: Four degrees and beyond: the potential for a global temperature increase of four degrees and its implications. *Philosophical Transactions of the Royal Society*, **369**, 6-19.

National Research Council, 1996: *Understanding Risk: Informing Decisions in a Democratic Society.* Committee on Risk Characterization, National Research Council, National Academy Press, Washington, DC, USA, 250 pp.

National Research Council, 1999: *Our Common Journey: A Transition Toward Sustainability.* Board on Sustainable Development, National Research Council, National Academies Press, Washington, DC, USA, 350 pp.

National Research Council, 2010a: *Adapting to Impacts of Climate Change.* Report of the Panel on Adapting to the Impacts of Climate Change, NAS/NRC Committee on America's Climate Choices, National Research Council, Washington, DC, USA, 292 pp.

National Research Council, 2010b: *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia.* Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations, National Research Council, National Academies Press, Washington, DC, USA, 298 pp.

National Research Council, 2011: *America's Climate Choices.* Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, National Research Council, National Academies Press, Washington, DC, USA, 144 pp.

O'Brien, K., 2009: Do values subjectively define the limits to climate change adaptation? In: *Adapting to Climate Change: Thresholds, Values, Governance* [Adger, N.W., J. Lorenzoni, and K. O'Brien (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 164-180.

O'Brien, K., 2012: Global environmental change II: from adaptation to deliberate transformation. *Progress in Human Geography*, **36(5)**, 667-676.

O'Brien, K. and R.M. Leichenko, 2003: Winners and losers in the context of global change. *Annals, Association of American Geographers*, **93(1)**, 89-103.

O'Brien, K. and L. Sygna, 2013: Responding to climate change: the three spheres of transformation. In: *Proceedings* of *Transformation in a Changing Climate, June 19-21, Oslo, Norway*. University of Oslo, Department of Sociology and Human Geography, Oslo, Norway, pp.16-23.

O'Brien, K.L., A.L. St. Clair, and B. Kristoffersen (eds.), 2010: *Toward a New Science on Climate Change.* Cambridge University Press, Cambridge, UK, pp. 215-227.

O'Hara, P.A., 2009: Climate change and political economy. *Ecological Economics*, **69**, 223-234.

Oliver-Smith, A., S.L. Cutter, K. Warner, C. Corendea, and K. Yuzva, 2012: *Addressing Loss and Damage in the Context of Social Vulnerability and Resilience.* United Nations University Institute for Environment and Human Security (UNU-EHS), Bonn, Germany, pp. 3-35.

Omolo, N., 2010: Gender and climate change-induced conflict in pastoral communities: case study of Turkana in Northwestern Kenya. *African Journal on Conflict Resolution*, **10(2)**, 81-102.

Ostrom, E., 1986: An agenda for the study of institutions. *Public Choice*, **48**, 3-25.

Park, S.E., N.A. Marshall, E. Jakku, A.M. Dowd, S.M. Howden, E. Mendham, and A. Fleming, 2012: Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change*, **22**, 115-126.

Patel, P. and K. Pavit, 1995: Patterns of technological activity: their measurement and interpretation. In: *Handbook of Economics of Innovation and Technological Change* [Stone, P. (ed.)]. Blackwell Handbooks in Economics, Blackwell Publishers, Ltd., Oxford, UK, pp. 14-51.

Pelling, M., 2010: *Adaptation to Climate Change: From Resilience to Transformation.* Routledge, Abingdon, UK and New York, NY, USA, 224 pp.

Pelling, M., C. High, J. Dearing, and D. Smith, 2007: Shadow spaces for social learning: a relational understanding of adaptive capacity to climate change within organizations. *Environment and Planning A*, **40**, 867-884.

Perez, C., 2002: *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages.* Edward Elgar, Northampton, MA, USA, 198 pp.

Peters, G.P., R.M. Andrew, T. Boden, J.G. Canadell, P. Ciais, C. Le Quéré, G. Marland, M.R. Raupach, and C. Wilson, 2013: The challenge to keep global warming below 2ºC. *Nature Climate Change*, **3**, 4-6.

Pintér, L., P. Hardi, A. Martinuzzi, and J. Hall, 2011: Bellagio STAMP: principles for sustainability assessment and measurement. *Ecological Indicators*, **17**, 20-28.

Pramova, E., B. Locatelli, I.H. Djoud, and O. Somorin, 2012: Forests and trees for social adaptation to climate variability and change. *Wiley Interdisciplinary Reviews: Climate Change*, **2(1)**, 434-450.

Preston, B.L., K. Dow, and F. Berkhout, 2013: The climate adaptation frontier. *Sustainability*, **5(3)**, 1011-1035, doi:10.3390/su5031011.

Pyke, C.R., B.G. Bierwagen, J. Furlow, J. Gamble, T. Johnson, S. Julius, and J. West, 2007: A decision inventory approach for improving decision support for climate change impact assessment and adaption. *Environmental Science & Policy*, **10(7-8)**, 610-621.

Rabbani, G., A. Rahman, and K. Mainuddin, 2013: Salinity-induced loss and damage to farming households in coastal Bangladesh. *International Journal of Global Warming*, **5(4)**, 400-415.

Rao, P.K., 2000: *Sustainable Development: Economics and Policy.* Blackwell Publishers, Ltd., Oxford, UK, 393 pp.

Raven, R., S. van den Bosch, and S. Weterings, 2010: Transitions and strategic niche management: towards a competence kit for practitioners. *International Journal of Technology Management*, **51(1)**, 57-74.

Riahi, K., 2000: Energy technology strategies for carbon dioxide mitigation and sustainable development. *Environmental Economics and Policy Studies*, **32(2)**, 89-123.

Riahi, K., S. Rao, V. Krey, C. Cho, V. Chirkov, G. Fischer, G. Kindermann, N. Nakicenovic, and P. Rafaj, 2011: RCP 8.5 – a scenario of comparatively high greenhouse gas emissions. *Climatic Change*, **109(1-2)**, 33-57.

Roberts, J.T. and B.C. Parks, 2006: *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy.* MIT Press, Cambridge, MA, USA, 404 pp.

Robinson, J., 2004: Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, **48**, 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)**, 2-8.

Robock, A., L. Oman, and G. Stenchikov, 2008: Regional climate responses to geoengineering with tropical and Arctic SO_2 injections. *Journal of Geophysical Research*, **113(D16)**, 27, doi:10.1029/2008JD010050.

Rockström, J., W. Steffen, K. Noone, A. Persson, F.S. Chapin III, E.F. Lambin, T.M. Lenton, M. Scheffer, C. Folke, H.J. Schellnhuber, B. Nykvist, C.A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P.K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R.W. Corell, V.J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J.A. Foley, 2009: A safe operating space for humanity. *Nature*, **461(282)**, 472-475.

Rogelj, J., D.L. McCollum, A. Reisinger, M. Meinshausen, and K. Riahi, 2013: Probabilistic cost estimates for climate change mitigation. *Nature*, **493**, 79-83.

Rohracher, H., 2008: Energy systems in transition: contributions from social sciences. *International Journal of Environmental Technology and Management*, **9(203)**, 144-161.

Romero-Lankao, P. and T.J. Wilbanks, 2011: Linkages between climate change responses, research and policy directions. In: *Global Report on Human Settlements 2011: Cities and Climate Change.* UN Human Settlements Programme (UN-HABITAT), Earthscan, London, UK and Washington, DC, USA, pp. 163-183.

Rose, S., 2010: *The Importance of Multi-metric, Scale, and Sector Climate Change Impacts Valuation*. Presentation prepared for the Energy Modeling Forum (EMF) Workshop: Climate Change Impacts and Integrated Assessment (CCIIA), July 27-August 4, Snowmass, CO, USA, emf.stanford.edu/files/docs/259/Rose7-28.pdf.

Rosenzweig, C. and F.N. Tubiello, 2007: Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. *Mitigation and Adaptation Strategies for Global Change*, **12**, 855-873.

Rounsevell, M.D.A., T.P. Dawson, and P.A. Harrison, 2010: A conceptual framework to assess the effects of environmental change on ecosystem services. *Biodiversity and Conservation*, **19**, 2823-2842.

Rowe, G. and L.J. Frewer, 2004: Evaluating public participation exercises: a research agenda. *Science, Technology, and Human Values*, **29(4)**, 512-556.

Roy, M., 2009: Planning for sustainable urbanization in fast growing cities: mitigation and adaptation issues addressed in Dhaka, Bangladesh. *Habitat International*, **33(3)**, 276-286.

Saito, N., 2013: Mainstreaming climate change adaptation in least developed countries in South and Southeast Asia. *Mitigation and Adaptation Strategies for Global Change*, **18(6)**, 825-849.

Salter, J., J. Robinson, and A. Wick, 2010: Participatory methods of integrated assessment: a review. *Wiley Interdisciplinary Reviews: Climate Change*, **1**, 697-717.

Sanwal, M., 2012: Rio +20, climate change and development: the evolution of sustainable development (1972-2012). *Climate and Development*, **42(2)**, 157-166.

Scheffer, M., J. Bascompte, W.A. Brock, V. Brovkin, S.R. Carpenter, V. Dakos, H. Held, E.H. van Nes, M. Rietkerk, and G. Sugihara, 2009: Early-warning signals for critical transitions. *Nature*, **461**, 53-59.

Schipper, L., 2007: *Climate Change Adaptation and Development: Exploring the Linkages*. Working Paper No. 107, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK, 13 pp.

Schipper, L. and M. Pelling, 2006: Disaster risk, climate change and international development: scope for, and challenges to integration. *Disasters*, **30(1 SI)**, 19-38.

Schlager, E. and T. Heikkila, 2011: Left high and dry? Climate change, common pool resource theory and the adaptability of western water compacts. *Public Administration Review*, **71(3)**, 461-470.

Schlitz, M.M., C. Vieten, and E.M. Miller, 2010: Worldview transformation and the development of social consciousness. *Journal of Consciousness Studies*, **17(7-8)**, 18-36.

Schneider, S., 1996: Geoengineering: could – or should – we do it? *Climatic Change*, **33**, 291-302.

Schneider, S., 2008: Geoengineering: could we or should we make it work? *Philosophical Transactions of the Royal Society A*, **366**, 3843-3862.

Schoolmaster, D.R., J.B. Grace, E.W. Schweiger, G.R. Guntenspergen, B.R. Mitchell, K.M. Miller, and A.N. Little, 2013: An algorithmic and information-theoretic approach to multimetric index construction. *Ecological Indicators*, **26**, 14-23.

Scrieciu, S., T. Barker, and F. Ackerman, 2013: Pushing the boundaries of climate economics: critical issues to consider in climate policy analysis. *Ecological Economics*, **85**, 155-165.

Seballos, F. and S. Kreft, 2011: Towards an understanding of the political economy of the PPCR. *IDS Bulletin*, **42(3)**, 33-41.

Sen, A., 1999: *Development as Freedom.* Alfred A. Knopf, Inc., New York, NY, USA, 366 pp.

Senaratne, A. and K. Wickramasinghe, 2010: Climate change, local institutions and adaptation experience: the village tank farming community in the dry zone of Sri Lanka. In: *Proceedings of the National Conference on Water, Food Security, and Climate Change in Sri Lanka, BMICH, Colombo, June 9-11, 2009: Volume 2. Water Quality, Environment, and Climate Change* [Evans, A. and K. Jinapala (eds.)]. International Water Management Institute (IWMI), Battaramulla, Sri Lanka, pp. 147-174.

Seto, K.C., R. Sanchez-Rodriguez, and M. Fragkias, 2010: The new geography of contemporary urbanization and the environment. *Annual Review of Environment and Resources*, **35**, 167-194.

Shah, T., 2009: Climate change and groundwater: India's opportunities for mitigation and adaptation. *Environmental Research Letters*, **4(3)**, 035005, doi:10.1088/1748-9326/4/3/035005.

Sheppard, S. and M. Meitner, 2005: Using multi-criteria analysis and visualization for sustainable forest management planning with stakeholder groups. *Forest Ecology and Management*, **207(1-2)**, 171-187.

Shove, E. and G. Walker, 2010: Governing transitions in the sustainability of everyday life. *Research Policy*, **39**, 471-476.

Sietz, D., M. Boschütz, and R.J.T. Klein, 2011: Mainstreaming climate adaptation into development assistance: rationale, institutional barriers and opportunities in Mozambique. *Environmental Science & Policy*, **14(4)**, 493-502.

Sitarz, D. (ed.), 1994: *Agenda 21: The Earth Summit Strategy to Save our Planet.* EarthPress, Boulder, CO, USA, 321 pp.

Smit, B. and O. Pilifosova, 2001: Adaptation to climate change in the context of sustainable development and equity. In: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of the Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J., O. Canziani, N. Leary, D. Dokken, and K. White (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 879-912.

Smit, B. and J. Wandel, 2006: Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, **16(3)**, 282-292.

Smith, A. and A. Stirling, 2010: The politics of social-ecological resilience and sustainable socio-technical transitions. *Ecology and Society*, **15(1)**, 11, www.ecologyandsociety.org/vol15/iss1/art11/.

Smith, J.B., S.H. Schneider, M. Oppenheimer, G.W. Yohe, W. Hare, M.D. Mastrandrea, A. Patwardan, I. Burton, J. Corfee-Morlot, C.H.D. Magadza, H.-M. Füssel, A.B. Pittock, A. Rahman, A. Suarez, and J.-P. vanYpersele, 2009: Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) "reasons for concern". *Proceedings of the National Academy of Sciences of the United States of America*, **106**, 4133-4137.

Smith, M., L. Horrocks, A. Harvey, and C. Hamilton, 2011: Rethinking adaptation for a 4°C world. *Philosophical Transactions of the Royal Society A*, **369(1934)**, 196-216.

Sosa-Rodriguez, F.S., 2013: From federal to city mitigation and adaptation: climate change policy in Mexico City. *Mitigation and Adaptation Strategies for Global Change*, doi:10.1007/s11027-013-9455-1.

Stafford, S.G., D.M. Bartels, S. Begay-Campbell, J.L. Bubier, J.C. Crittenden, S.L. Cutter, J.R. Delaney, T.E. Jordan, A.C. Kay, G.D. Libecap, J.C. Moore, N.N. Rabalais, D. Rejeski, O.E. Sala, J.M. Shepherd, and J. Travis, 2010: Now is the time for action: transitions and tipping points in complex environmental systems. *Environment*, **52(1)**, 38-45.

Stern, P.C. and T. J. Wilbanks, 2009: Appendix D: Fundamental research priorities to improve the understanding of human dimensions of global change. In: *Restructuring Federal Climate Research to Meet the Challenges of Climate Change*. Committee on Strategic Advice on the U.S. Climate Change Science Program, Division on Earth and Life Studies, Division of Behavioral and Social Sciences and Education, National Research Council, National Academies Press, Washington, DC, USA, pp. 167-202.

Stoorvogel, J.J., J.M. Antle, C.C. Crissman, and W. Bowen, 2004: The tradeoff analysis model: integrated bio-physical and economic modeling. *Agricultural Systems*, **80**, 43-66.

Stringer, L.C., J.C. Dyer, M.S. Reed, A.J. Dougill, C. Twyman, and D. Mkwambisi, 2009: Adaptations to climate change, drought and desertification: local insights to enhance policy in Southern Africa. *Environmental Science & Policy*, **12(7)**, 748-765.

Sutter, C. and J.C. Parreño, 2007: Does the current Clean Development Mechanism (CDM) deliver its sustainable development claim? An analysis of officially registered CDM projects. *Climatic Change*, **84**, 75-90.

Swart, R. and F. Raes, 2007: Making integration of adaptation and mitigation work: mainstreaming into sustainable development policies? *Climate Policy*, **7**, 288-303.

Swart, R., J. Robinson, and S. Cohen, 2003: Climate change and sustainable development: expanding the options. *Climate Policy*, **3(Suppl. 1)**, S19-S40.

Tanner, T. and J. Allouche, 2011: Towards a new political economy of climate change and development. *IDS Bulletin*, **42(3)**, 1-14, doi: 10.1111/j.1759-5436.2011.00217.x.

Tejero, I.G., V.H.D. Zuazo, J.A.J. Bocanegra, and J.A.L. Fernández, 2011: Improved water-use efficiency by deficit irrigation programmes: implications for saving water in citrus orchards. *Scientia Horticulturae*, **128(3)**, 274-282.

Thomalla, F., T. Downing, E. Spanger-Siegfried, and G. Han, 2006: Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. *Environment*, **30(1)**, 39-48.

Thomas, D.S.G. and C. Twyman, 2005: Equity and justice in climate change adaptation amongst natural-resource-dependant societies. *Global Environmental Change*, **15(2)**, 115-124.

Tol, R.S.J., 2004: Adaptation and mitigation: trade-offs in substance and methods. *Environmental Science and Policy*, **8**, 572-578.

Tompkins, E.L. and W.N. Adger, 2004: Does adaptive management of natural resources enhance resilience to climate change? *Ecology and Society*, **9**, 2-10.

Tompkins, E.L., M.C. Lemos, and E. Boyd, 2008: A less disastrous disaster: managing response to climate-driven hazards in the Cayman Islands and NE Brazil. *Environmental Change*, **18(4)**, 736-745.

Traore, S. and T. Owiyo, 2013: Dirty droughts causing loss and damage in Northern Burkina Faso. *International Journal of Global Warming*, **5(4)**, 498-513.

Turner, W.R., B.A. Bradley, L.D. Estes, D.G. Hole, M. Oppenheimer, and D.S. Wilcove, 2010: Climate change: helping nature survive the human response. *Conservation Letters*, **3(5)**, 304-312.

UK Royal Society, 2009: *Geoengineering the Climate: Science, Governance, and Uncertainty.* The Royal Society, London, UK, 82 pp.

UN-REDD Programme, 2013: *UN-REDD Programme*, *Multiple Benefits*. United Nations Environment Programme (UNEP), United Nations (UN) collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries, UN-REDD Programme, UN-REDD Programme Secretariat, Geneva, Switzerland.

UNFCCC, 2011: *Assessing the Costs and Benefits of Adaptation Options: An Overview of Approaches.* United Nations Framework Convention on Climate Change (UNFCCC), UNFCCC Secretariat, Bonn, Germany, 48 pp.

Vaughan, N. and T. Linten, 2011: A review of climate geoengineering proposals. *Climatic Change*, **109**, 745-790.

Veeman, T.S. and J. Politylo, 2003: The role of institutions and policy in enhancing sustainable development and conserving natural capital. *Environment, Development and Sustainability*, **5**, 317-332.

Vergara, W., A.R. Rios, L.M. Galindo, P. Gutman, P. Isbell, P. Suding, A. Grunwaldt, A. Deeb, J. Samaniego, E. Allatorre, and M. Panuncio, 2012: *The Climate and Development Challenge for Latin America and the Caribbean: Options for Climate-Resilient*, *Low-Carbon Development.* Inter-American Development Bank (IADB) in collaboration with the Economic Commission of Latin America and the Caribbean (ECLAC) and the World Wildlife Fund (WWF), IADB, Washington, DC, USA, 103 pp.

Victor, P., 2008: *Managing Without Growth: Slower by Design, Not Disaster.* Edward Elgar, Cheltenham, UK and Northampton, MA, USA, 272 pp.

Victor, P. and G. Rosenbluth, 2007: Managing without growth. *Ecological Economics*, **61**, 492-504.

Viguié, V. and S. Hallegatte, 2012: Trade-offs and synergies in urban climate policies. *Nature Climate Change*, **5**, 334-337.

Von Bernard, H. and M. Gorboran, 2010: Causes for unsustainability. *Ecología Austral*, **20(3)**, 303-306.

Walker, B. and D. Salt, 2006: *Resilience Thinking: Sustaining Ecosystems and People in a Changing World.* Island Press, Washington, DC, USA, 174 pp.

Warner, K. and T. Afifi, 2013: Where the rain falls: evidence from 8 countries on how vulnerable households use migration to manage the risk of rainfall variability and food insecurity. *Climate and Development* (in press), doi:10.1080/17565529.2013.835707.

Warner, K. and K. van der Geest (eds.), 2013: Loss and damage from climate change: local-level evidence from nine vulnerable countries. *International Journal of Global Warming*, **5(4)**, 367-386.

Warner, K., S. Kreft, M. Zissener, P. Höppe, C. Bals, T. Loster, J. Linnerooth-Bayer, S. Tschudi, E. Gurenko, A. Haas, S. Young, P. Kovacs, A. Dlugolecki, and A. Oxley, 2012a: *Insurance Solutions in the Context of Climate Change-Related Loss and Damage.* Policy Brief No. 6, The Munich Climate Insurance Initiative (MCII), hosted by the United Nations University Institute for Environment and Human Security (UNU-EHS), UNU-EHS, Bonn, Germany, 48 pp.

Warner, K., K. van der Geest, S. Kreft, S. Huq, S. Harmeling, K. Kusters, and A. de Sherbinin, 2012b: *Evidence from the Frontlines of Climate Change: Loss and Damage to Communities Despite Coping and Adaptation*. Loss and Damage in Vulnerable Countries Initiative, Policy Report No. 9, United Nations University Institute for Environment and Human Security (UNU-EHS), UNU-EHS, Bonn, Germany, 86 pp.

Washington, W.M., R. Knutti, G.A. Meehl, H. Teng, C. Tebaldi, D. Lawrence, J. Buja, and W.G. Strand, 2009: How much climate change can be avoided by mitigation? *Geophysical Research Letters*, **36(8)**, L08703, doi:10.1029/2008GL037074.

WCED, 1987: *Our Common Future.* Report of the World Commission on Environment and Development, Annex to General Assembly document A/42/427, Development and International Co-operation: Environment, World Commission on Environment and Development (WCED), Oxford University Press, London, UK, 383 pp.

Westley, F., P. Olsson, C. Folke, T. Homer-Dixon, H. Vredenburg, D. Loorbach, J. Thompson, M. Nilsson, E. Lambin, J. Sendzimir, B. Banerjee, V. Galaz, and S. van der Leeuw, 2011: Tipping toward sustainability: emerging pathways of transformation. *Ambio*, **40(7)**, 762-780.

WHO, 2011: *Health in the Green Economy: Health Co-Benefits of Climate Change Mitigation –Transport Sector* [Hosking, J., M. Pierpaolo, and C. Dora, (eds.)]. World Health Organization (WHO), Geneva, Switzerland, 144 pp.

Wilbanks, T.J., 2003: Integrating climate change and sustainable development in a place-based context. *Climate Policy*, **3(Suppl. 1)**, S147-S154.

Wilbanks, T.J., 2009: *How Geographic Scale Matters in Seeking Community Resilience.* CARRI Research Paper No. 7, Community and Regional Resilience Initiative (CARRI), Oak Ridge, TN, USA, 13 pp.

Wilbanks, T.J., 2010: Inducing transformational energy technological change. *Energy Economics*, **33(4)**, 699-708.

Wilbanks, T.J. and R.W. Kates, 2010: Beyond adapting to climate change: embedding adaptation in responses to multiple threats and stresses. *Annals Association of American Geographers*, **100(4)**, 719-728.

Wilbanks, T.J. and J. Sathaye, 2007: Integrating mitigation and adaptation as responses to climate change: a synthesis. *Mitigation and Adaptation Strategies for Global Change*, **12**, 957-962.

Wilbanks, J.T. and T.J. Wilbanks, 2010: Science, open communication, and sustainable development. *Sustainability*, **2(4)**, 993-1015.

Wilbanks, T.J., P. Leiby, R.D. Perlack, J.T. Ensminger, and S.B. Wright, 2007: Toward an integrated analysis of mitigation and adaptation: some preliminary findings *Mitigation and Adaptation Strategies for Global Change*, **12(5)**, 713-725.

Wilson, C. and T. McDaniels, 2007: Structured decision-making to link climate change and sustainable development. *Climate Policy*, **7(4)**, 353-370.

Winkelman, A.G. and M.R. Moore, 2011: Explaining the differential distribution of Clean Development Mechanism projects across host countries. *Energy Policy*, **39**, 1132-1143.

Winkler, H., K. Baumert, O. Blanchard, S. Burch, and J. Robinson, 2007: What factors influence mitigative capacity? *Energy Policy*, **35**, 692-703.

Wolf, J., K. Brown, and D. Conway, 2009: Ecological citizenship and climate change: perceptions and practice. *International Politics*, **18(4)**, 467-485.

World Bank, 2010: *World Development Report: Development and Climate Change.* The International Bank for Reconstruction and Development / The World Bank, Washington, DC, USA, 417 pp.

Xiong, W., L. Holman, and E.D. Lin, 2010: Climate change, water availability, and future cereal production in China. *Agriculture, Ecosystems, and Environment*, **135**, 58-69.

Yaffa, S., 2013: Coping measures not enough to avoid loss and damage from drought in the North Bank region of the Gambia. *International Journal of Global Warming*, **5(4)**, 467-482.

Yohe, G., 2001: Mitigative capacity: the mirror image of adaptive capacity on the emissions side. *Climatic Change*, **49**, 247-262.

Yohe, G., 2012: Economics and environmental studies. *Review of Development Economics*, **16(3)**, 503-510.

Yohe, G. and R. Tol, 2002: Indicators for social and economic coping capacity: moving toward a working definition of adaptive capacity. *Global Environmental Change*, **12**, 25-40.

Younger, M., H.R. Morrow-Almeida, S.M. Vindigni, and A.L. Dannenberg, 2008: The built environment, climate change, and health: opportunities for co-benefits. *American Journal of Preventive Medicine*, **35(5)**, 517-526.

Ziervogel, G. and A. Opere (eds.), 2010: *Integrating Meteorological and Indigenous Knowledge-Based Seasonal Climate Forecasts in the Agricultural Sector: Lessons from Participatory Action Research in Sub-Saharan Africa.* Climate Change Adaptation in Africa (CCAA) Learning Paper, International Development Research Centre (IDRC), Ottawa, ON, Canada, 19 pp.

Zou, X., Y. Li, Q. Gao, and Y. Wan, 2012: How water saving irrigation contributes to climate change resilience: a case study of practices in China. *Mitigation and Adaptation Strategies for Global Change*, **17(2)**, 111-132.