Chapter 20. 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 for development are evolutionary processes for managing change within complex systems. They are rooted in iterative processes of identifying vulnerabilities to climate change impacts; taking appropriate steps (a) to reduce vulnerabilities in the context of development needs and resources and (b) to increase the options available for vulnerability reduction and coping with surprises. Such responses include monitoring emerging climate parameters and their implications, monitoring the effectiveness of vulnerability reduction efforts (including both adaptation and mitigation), and revising risk reduction responses on the basis of continuing learning. Because uncertainties about climate effects and other driving forces affecting development are likely to make conventional development interventions (e.g. specific, multi-decadal strategies and annual or multi-year static plans) non-sustainable over time, fostering climate will require innovative approaches. This process may involve a combination of incremental changes and, as necessary, significant transformations. Such processes and responses will include both climate change risk reduction through mitigation and adaptation and also changes in sustainable development pathways themselves to increase their resilience.

This 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 to cope with impacts that cannot be (or are not) avoided, and elements of sustainable development pathways that contribute to climate-resilience. In most cases, vulnerability reduction and appropriate risk management approaches will differ from situation to situation, calling for a multi-scale perspective built solidly on fine-grained contextual realities. But most situations share at least one fundamental characteristic: threats to sustainable development are greater if climate change is substantial than if it is moderate – and opportunities for sustainable development are greater if climate change is moderate rather than substantial.

This chapter's assessment findings are the following. Although they are based on a high level of consensus in source materials and in the expert communities, the amount of supporting evidence is usually limited by the fact that so many aspects of sustainable development and climate change mitigation and adaptation, considered together over periods many decades into the future, are surrounded by issues that are beyond past and current observation and experience. The task of this chapter is to move out into uncharted territory.

Because climate change is a growing threat to development, it is a high priority to identify and pursue climate-resilient pathways for sustainable development (*high confidence*; *high agreement, medium evidence*). Because climate change can no longer be avoided, some impacts on development are already being observed, and they are virtually certain to increase. Added to other stresses on sustainable development, effects of climate change will make sustainability more difficult to achieve for many locations, systems, and affected populations, related to such objectives as poverty reduction, health, and livelihood security; but climate-resilient pathways can improve prospects for sustainable development. [20.2]

Climate-resilient pathways include (a) actions to reduce climate change and its impacts and (b) actions to assure that effective risk management and adaptation can be implemented and sustained (*high confidence*;

***high agreement, medium evidence*).** 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. Both kinds of responses are needed, working together to reduce risks of disruptions from climate change. [20.3, 20.4]

In some cases, each of the two categories of responses is likely to benefit the other as well, offering potentials for co-benefits from integration (*moderately high confidence*; *medium high agreement, medium evidence*). Development pathways that are resilient with respect to a wide range of challenges and threats are more likely to be climate-resilient, while climate change risk reduction can contribute to strengthening capacities for risk management in other regards as well. Strategies to achieve each goal have the potential to reinforce the other, but windows of opportunity may narrow with time. [20.2.1, 20.3.3]

Prospects for climate-resilient development pathways are related fundamentally to what the world accomplishes with climate change mitigation (*high confidence*; *high agreement, medium evidence*). As the magnitude of climate change grows, the challenges to climate resilience grow; and above some high level of climate change, the impacts on most systems would be great enough that climate-resilience is no longer possible for many systems and locations. [20.6.1]

Because climate change vulnerabilities are significant for many areas, systems, and populations, climate-resilient pathways will often require transformations in order to assure sustainable development (*high confidence*; *high agreement, medium evidence*). Significantly large and/or rapid increases in climate extremes and climate-related extreme weather events are less amenable to incremental adaptations to climate change and will often require more transformational change if development is to be sustained without major disruptions. [20.5]

At a global scale, climate-resilient pathways will include both climate change adaptation and mitigation. At sub-global scales, climate-resilient pathways will involve a range of actions appropriate to potentials for vulnerability/risk reduction at those scales (*high confidence*; *high agreement, medium evidence*). Although at a global scale both mitigation and adaptation are essential, relatively local scales in many developing regions have limited capacities to include mitigation in their climate-resilience strategies because they contribute very little to the causes of climate change. At all scales, however, actions are important to assure that effective risk management can be implemented and sustained. [20.2.3, 20.6.1]

Although outcomes from specific actions are often uncertain, 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 (*high confidence*; *high agreement, medium evidence*). Actions at the present time will emphasize co-benefits and iterative learning, with risk management strategies and capacities refined continually on the bases of growing evidence, knowledge, and experience. [20.6.2]

Meanwhile, what is known about integrating climate change mitigation, climate change adaptation, and sustainable development is dwarfed by what is not known (*high confidence*; *high agreement, strong evidence*). Improving the base of knowledge about relationships and potentials for progress with climate resilience is a high priority, as a basis for adaptive learning and action. [20.7]

20.1. Introduction

Following summaries of *what we know* about climate change impacts, vulnerabilities, and prospects for adaptation (Chapter 18) and of *what we should be most worried about* (Chapter 19), this concluding topical chapter of the Working Group II Fifth Assessment Report 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 minimize climate change and threats to development now and in the future, this chapter identifies and discusses climate-resilient pathways. Climate-resilient pathways are evolutionary processes for managing change within complex systems in order to reduce disruptions and enhance opportunities. They are rooted in continuing, interactive processes of identifying vulnerabilities to climate change impacts; taking appropriate steps to reduce vulnerabilities in the context of development needs and resources, building capacity to increase the options available for vulnerability reduction and coping with unexpected threats; monitoring emerging climate parameters and their implications and the effectiveness of vulnerability reduction efforts; and revising risk reduction responses on the basis of continuing learning. This process may involve a combination of incremental changes and, as necessary, significant transformations (see sections 20.2.3.1 and 20.6.2; for related UNFCCC language, see Box 20-1). As such, climate-resilient pathways include two essential elements:

- Actions to reduce climate change and its impacts, including both mitigation and adaptation
- Actions to assure that effective risk management institutions, strategies, and choices will be identified, implemented, and sustained as an integrated part of development processes.

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Box 20-1. UNFCCC Goals for Climate-Resilient Pathways

Climate resilient pathways are trajectories of combined mitigation and adaptation that are consistent with the aims of sustainable development and which do not traverse the threshold of "dangerous anthropogenic interference with the climate system" as specified in Article 2 of the Convention.

Article 2 of the United Nations Framework Convention on Climate Change presents the 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.'* According to the Convention, the climate system must not be dangerous 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 recognizes that "Parties have a right to, and should promote sustainable development." The Copenhagen Accord of 2009 states, "To achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2 degrees Celsius, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change."

The Cancun Agreements Decision 1/CP.16 confirms this with a view that "… recognizes … 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, in the context of the first review… strengthening the long-term global goal on the basis of the best available scientific knowledge.

The 2011 Conference of the Parties 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 w*ith 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 pre-industrial levels. As such, the current UNFCCC negotiations have adopted +2°C or 1.5 C as the desirable target upper limit and equated this with "dangerous" in Article 2.

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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 assure that positive synergies are realized. Because climate change challenges are significant for many areas, systems, and populations, climate-resilient pathways will generally require transformations in order to assure sustainable development – beyond incremental approaches.

The chapter shows how climate-resilient pathways can recognize the relationship between mitigation, adaptation and sustainable development and invoke transformative actions to deliberately avoid dangerous climate change and its impacts. It examines the attributes and characteristics of pathways for sustainable development that are resilient to impacts of climate change, including potentials and possible limitations. In doing so, 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 to cope with impacts that cannot be (or are not) avoided, and development pathways as contexts that shape choices and actions.

The chapter is organized in six parts: climate change as a threat to sustainable development, assessing links between sustainable development and climate change as well as defining climate resilient pathways (20.2), contributions to resilience through climate change responses (20.3), contributions to resilience through sustainable development strategies and choices (20.4), determinants of resilience in the face of serious threats (20.5), challenges in moving toward climate-resilient pathways (20.6), and priority gaps in knowledge (20.7).

Several of the terms that are central to this chapter have been defined earlier in the Working Group 2 Fifth Assessment Report, including climate, adaptation, and mitigation. In addition, by "resilient" we mean a system's capacity to anticipate and reduce, cope with, and respond to and recover from disruptions (IPCC SREX, 2012). For literatures on "sustainable development," see section 20.2.1 below. A summary definition is development that achieves continuing improvements in human well-being and assures a sustainable relationship with a physical environment that is already under stress, reconciling tradeoffs among economic, environmental, and other social goals through institutional approaches that are equitable and participative in order themselves to be sustainable.

20.2. Climate Change as a Threat to Sustainable Development

Climate-resilient pathways bring together (a) sustainable development as the larger context for societies, regions, nations, and the global community with (b) climate change effects as threats to (and possibly opportunities for) sustainable development and responses to reduce those effects that would undermine future development and even offset already achieved gains.

20.2.1. Links between Sustainable Development and Climate Change

20.2.1.1. Objectives of Sustainable Development

Understandings of sustainable development have developed considerably, particularly over the past two 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, 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 WG II and III reports, with a focus on both climate-first and development-first literatures, although integration of the two working group perspectives remains a work in progress.

"Sustainable development" is a concept rooted in many decades of concerns about balance in the relationships between society and nature (e.g., Brown, 1981). These concerns grew during the 1960s and 1970s in connection with observations of a declining quality of the environment coupled with increasing needs for natural resources as human populations expand and energy-.and other input-intensive living standards rise. Early initiatives (particularly in industrialized countries) focused the quality of water, air, management of hazardous materials and other individual attributes of the environment. In those decades, some of the outcomes from the initiatives included an array of regulations intended to manage and improve resource management, a movement toward recycling of consumable resources, and an emphasis on renewable energy as a substitute for energy production that consumed non-renewable fossil fuel resources (Frey and Linke, 2002).

The Brundtland Report defines sustainable development as that which meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). The report recognizes that poverty is one of the main causes of environmental degradation and that equitable economic development is key to addressing environmental problems both in developing and developed region (Halsnaes et al., 2008; Lafferty and Meadowcroft, 2010). From a practical perspective, sustainable development has been "operationalized" through Agenda 21, which is a comprehensive plan of action adopted at the 1992 Earth Summit by more than 178 governments (Sitarz, 1994). In June 2012, participants in the "Rio+20" conference issued a statement urging countries to renew their commitment to sustainable development.

Although the existing global discourse and practice around sustainable development has helped to establish some commonly held principles, the concept itself remains elusive and contested (e.g., Hopwood, Mellow, and O'Brien, 2005; Jabareen, 2008). For example, sustainable development has been criticized as being vague and immeasurable; and its connections with continued economic growth have drawn suspicion from those who believe sustainable development is a strategy to slow or limit development in the developing world, those who think that current trends in consumption patterns are themselves non-sustainable (e.g., Robinson, 2004), and those who believe that current institutional controls and linkages are seriously counterproductive (Scrieciu et al., 2011; Barker, 2008; O'Hara, 2009). Whereas some authors equate sustainable development with equity and values through which climate policies can be implemented (see IPCC Working Group III: Chapter 4), in practice some national authorities interpret sustainable development as the goal of pursuing economic development through the models embraced in industrialized countries.

With time, two factors have become evident (Brown, 2011**;** Grist, 2008; Sanwal, 2012). First, development has the potential to fundamentally alter global environmental systems, including climates (IPCC, 2007); and second, the basic model of development continues to aspire to the fossil-fuel intensive systems in place in most industrialized countries – from food production, trade, transport, and household consumption. This model still largely define development processes in practice, adding to challenges in realizing "sustainable" development. Until these two factors are reconciled, it may be difficult to attain climate-resilient pathways in either industrialized or developing countries, with associated consequences (Marston, 2012; Grist, 2008**).**

One way that sustainable development pathways can contribute to climate resilience is by pursuing consumption patterns that assure social and economic development without being wasteful of natural resources and the environment. It is possible that, rather than letting consumption be driven by familiar patterns of resource demands, the desired objectives of consumption might be met in ways that require lesser quantities of resources and produce lesser quantities of environmental emissions (Kates, 2000; also see Leiserowitz, Kates, and Parris, 2005).

Overall, development is a means to social and economic ends, not (usually) an end in itself; the objective is to develop in order to increase the abundance and reliability of services that are important to well-being, such as food, shelter, productivity, and enjoyment (Sen, 1999; Morgan and Farsides, 2009). For example, we do not develop improved energy systems because we want to consume kilowatts of electricity for their own sake; we consume them because they deliver comfort, convenience, and other qualities that we desire (Von Bernard and Gorbaran, 2010). Within the context of a changing climate, continued use and unlimited expansion of the limited resources of this planet does not seem consistent either sustainable development or climate resilient development (Ehrenfeld, 2008; Gilbert, 2006; also see Victor, 2008 and Victor and Rosenbluth, 2007).

There is a growing debate about economic growth and material consumption. Sustainable development is all about lifestyles, ways of life, and human well-being, which in turn are associated with – but not necessarily defined by -- the consumption of natural and material resources (e.g., Easterlin, 1974 and 2001; Adger, 2010; also see IPCC Working Group III: Chapter 4). One point of view in social research suggests that ever-increasing material consumption does not necessarily bring greater happiness or satisfaction or material comfort (DeLeire and Kalil, 2010; Cafaro, 2010; Huesemann, 2006). On the other hand, in many cases growth in consumption, especially among populations with incomes rising from low levels, is greatly beneficial (Clark, Frijters, and Shields, 2008; and Deaton, 2008). Measuring human well-being as a dimension of sustainable development that is not entirely captured by monetary income and level of consumption remains both a challenge and a need (Dolan and White, 2007; Fleurbaey, 2009).

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

As the extent of implications of climate change 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 effects of climate change may derail current sustainable development policy and potentially offset already achieved gains (World Bank, 2010; also see Boxes 20-2 and 20-3). For example, effects of climate change on key ecological resources and systems can jeopardize sustainable development in systems closely linked to natural capital. 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, 2007). Third, many of the conditions that define vulnerability to climate impact and the ability to respond to them are firmly rooted in development processes (e.g., structural deficits and available assets and entitlements) (Brooks et al., 2005; Lemos et al., forthcoming; Chapter 15). 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 SRREN, 2012; also see Chapter 9). Fifth, because several of the desirable conditions for successful mitigation and adaptation may overlap with those of sustainable development (e.g. implementation of no-regrets interventions, equitable distribution of resources, increased adaptive capacity and livelihood capitals), systems where sustainable development has been prioritized may provide a more conducive context for the implementation of successful mitigation and adaptation (Brown, 2011). Finally, climate mitigation and adaptation, if planned and integrated well, have the potential to create opportunities to further foster sustainable development (see section 20.3.3 below). 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 SREX, 2012). Understanding how to enhance positive feedbacks between mitigation, adaptation, and sustainable development while minimizing negative feedbacks 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 (Boxes 20-2 and 20-3). While some of the links described above have been contemplated in the scholarly literature, there remain considerable gaps on our knowledge base to inform climate-resilient pathways.

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

Chapter 19 of this report identifies key vulnerabilities to climate change that might affect sustainable development. Recognizing that the distribution of such impacts can be uneven and variable across space, time, and a number of dimensions of vulnerability, the major concerns about effects on sustainable development include:

- Risks to glaciers and the human systems supported by their meltwater
- Risks from extreme weather events
- Deterioration of regional food security
- Increased water stress in some areas
- Impacts on human health
- Losses of endangered species and biodiversity.

Cross-cutting concerns include aggregate impacts, the distribution of impacts, and large-scale singular events associated with system thresholds and irreversible change.

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Box 20-3. Connecting Representative Concentration Pathways (RCPs) with Shared Socioeconomic Pathways (SSPs)

The climate change science community has developed a new set of visions of a range of climate futures, called "Representative Concentration Pathways" or RCPs, intended to replace the rich families of SRES scenarios (IPCC, 2000) that were used extensively by IPCC and others for a decade. As reported in Moss et al., 2010, the RCPs include four representative pathways to illustrate the range of possible climate futures, defined in terms of approximate radiative forcing levels. These scenarios represent a broad range of potential climate outcomes, both over the near term (to 2035) and longer term (2100 and beyond).

To accompany these RCPs and provide context for assessing impacts of such futures, the climate change science community is also developing a set of representative socioeconomic futures, reflecting different pathways of economic intensity, capacity for societal problem-solving, and other dimensions of socioeconomic futures, called Shared Socioeconomic Pathways (SSPs), each defined by a storyline and supported by qualitative and quantitative characterizations (Kriegler et al., 2012; Ebi et al., forthcoming; O'Neill et al., forthcoming). In principle, it will be possible to compare socioeconomic conditions (SSPs) with climate forcings (RCPs) to evaluate such issues as differences in needs and challenges for mitigation or the feasibility of adaptation associated with different contexts regarding driving forces (see section 20.6.1).

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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 (Schipper, 2007; Burton et al., 2002; Halsnaes and Verhagen, 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, Robinson, and Cohen, 2007; Garg et al., 2009; Metz and Kok, 2008; Lemos, et al., 2007). 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). Yet, whereas climate change impacts are often strongly correlated with threats to sustainability, the debate on climate change has tended to run separately from the wider sustainability discourse (Cohen et al., 1998; IPCC, 2001). 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: 317; also see Matthew and Hammill, 2009). Especially in less developed countries/regions, the relationship between vulnerability to climate impacts and development is often inclusive 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, unequal power relations and weak democracy fundamentally shape sensitivity, exposure and adaptive capacity to climate impact – along with other factors influencing risks (Garg et al., 2009; McSweeny and Coomes, 2011; Adger et al., 2003; Kates, 2000). In these regions, reducing risks that affect resource-dependent communities is increasingly viewed as a necessary,but insufficient way to tackle the myriad of 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, climate forecasts) (Mirza, 2003; Schipper and Pelling, 2006). Hence, especially in less developed regions, it is important not only to understand 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., forthcoming).

While research increasingly highlights the intersection between vulnerability, adaptive capacity and developmental structural deficits, however, there is also growing recognition that the intractability of many of these problems may inhibit the development of climate-resilient pathways. For example, research by Wolf et al. (2009) on climate change responses in western Canada shows that self-efficacy and 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 their participation in designing solutions. Research focusing on disaster response in Mexico shows that alienation of individuals is instrumental to creating a compliant citizenry, and that resilience is undermined by a limited breadth of learning and experimentation, centralized power, and limited economic diversity (Pelling and Navarrete, 2011). In Northeast Brazil, the fact that local traditional politics relied on client-list relationships with drought-affected households to maintain power suggests that there was little incentive for policies that dramatically decreased their level of vulnerability (Tompkins, Lemos, and Boyd, 2008). Omolo (2010) argues that in the 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, in that some strategies and actions may have negative impacts on the well-being of others and future generations (Eriksen et al., 2011; Gardiner et al., 2010). For example, some mitigation measures, such as changing the composition of the atmosphere through geoengineering, could influence large-scale weather systems and create potentially dangerous conditions or new problems for many others (Gardiner et al., 2010, Carlin, 2007; Brovkin et al., 2009; de Sherbinin et al., 2011; also see Box 20-6). Likewise, some adaptation measures, such as using more surface water or groundwater for irrigation, may have negative effects on other users and more rapidly deplete scarce natural resources that could come under increasing pressure with climate change (Eriksen et al., 2011). The consequences of responses to climate change, whether related to mitigation or adaptation, can negatively influence future vulnerability, unless they are linked to the wider context of sustainable development (Bizikova et al., 2010). 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). 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; also see 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. 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 and the way to assess them to promote sustainable responses to climate change that contribute to resilience (Meadowcroft, 2000; Tompkins and Adger, 2004; Pinter et al., 2011).

A reality in many countries may be that development – which seeks to increase economic wealth – can enhance the capacity to adapt while at the same time adding to greenhouse gas 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 REDD (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries). And while vulnerable sectors such as agriculture give us particular reasons for concern (see Box 20-4), 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. These kinds of possible implications of climate change connect with drivers of sustainable development, and in turn social and economic dimensions of development affect the likelihood of effective responses to climate change risks (see Box 20-4). Moreover, some interventions related to climate change responses aim to combine goals of sustainable development, climate change adaptation, and climate change mitigation into “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, Stephenson, and Stephens, 2007), which 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 that while the goal of offsetting carbon emissions has been relatively successful, generating sustainable development dividend has been difficult. For example, after examining sixteen existing CDM projects around the world, Sutter and Parreno (2007) found that whereas they are likely to meet 72% of their emissions reduction goals, less than 1% iarelikely contribute significantly to sustainable development in the host country. Furthermore, their research suggests that there might be an actual tradeoff between the goals of efficient generation of carbon emissions certificates (CERs) and the broader generation of the sustainable development dividend (also see Winkelman and Moore, 2011). 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 combine mitigation and sustainable development such as the CDM are not achieving their win-win goals indicates the need for rapidly developing means for evaluating, changing and improving what is not working (Pressman and Wildavsky, 1984).

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Box 20-4. Case Studies from China

Water-saving irrigation has enhanced the 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 2007-2009 added up to 30.7-34.92 Gm^3 for each year, which accounted for 5.6%~11.8% of the national total water consumption. For example in 2009, according to current agricultural water consumption conditions, the saved water enabled expansions of the irrigated cropland by 3.80-7.80 Mhm^2 and increase grain production by 14.68-30.15 Mt, enough to meet one year grain needs of 73-151 million people (Zou et al., 2012) (Table 20-1). Besides, the performance of water saving irrigation from 2007-2009 saved about 9.59-20.85 Mt of standard coal and reduced 21.83-47.48Mt CO_2 emissions, which not only alleviated electric and diesel pressure in rural area but also reduced agricultural GHG emissions Therefore, water-saving irrigation has had a positive effecct in dealing with climate change and sustainable development (Zou et al., 2012).
  [INSERT TABLE 20-1 HERE
  Table 20-1: Effectiveness of water-saving irrigation dealing with climate change (Zou et al., 2012).]
- ***Water-Saving Irrigation Measures in Alpine Grassland for Adapting to Climate Change***
  Northern Tibet is the headwater region for the Yangtze, Nu (Salween River), Lancang (Mekong River), and numerous other rivers and high mountain lakes (Gao et al., 2009). Sustaining environmental conditions in the region is of vital importance not only for Tibet but also for China as a whole. Being a fragile ecosystem,

the alpine grassland ecosystem in Northern Tibet is extremely sensitive to climate change and human activity. In recent years, the rise in precipitation and temperature results has led to the melting of glaciers and expansion of 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). A three-year demonstration of alpine grassland water-saving irrigation measures showed that alpine grassland yield nearly doubled (Figure 20-1b) while the plant species increased from 19 to 29, helping to protect and restore the alpine grassland ecosystem and ecosystem services and to promote regional socio-economic sustainable development in Northern Tibet (Gao et al., 2012).

[INSERT FIGURE 20-1 HERE
Figure 20-1: The demonstration of alpine grassland water-saving irrigation measures for adaptation to climate change in Northern Tibet.]

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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. One option is the "development first" approach which suggests that the incorporation of climate concerns within prevalent development interventions is the best option, since development is usually the highest priority (Kok et al., 2008). In this approach, governments take into consideration tradeoffs between different dimensions of sustainability and look for climate-inclusive policy options that offer positive synergies with development, aiming at both low greenhouse gas emissions and low vulnerabilities to climate impacts (if their development paradigms are flexible enough to expand in such a way). Lessons from this literature also emphasize the contextual and place-based character of these processes and the need to understand opportunities and constraints relative to local, national, and global priorities (Wilbanks and Sathaye, 2007). Factors constraining the 'mainstreaming' of climate adaptation into development include discrepancies between immediate development goals and future climate change scenarios, especially in less developed regions and emerging economies. They also include a growing disconnect between donors' goals and developing countries' own development agendas (Agrawala, 2004; Klein, Schipper, and Desai, 2005), potentially inhibiting the development of robust local institutions that can effectively integrate or mainstream climate change policy into to their development priorities. Many developing countries lack technical assistance and capacity development to support their climate change agendas and to identify and manage risks. Often, programs tend to be poorly coordinated, fragmented, and bureaucratic, thus accentuating the isolation that vulnerable communities feel with regard to access to such programs, and even where programs are reasonably well-coordinated bureaucratic complexities can cause communities to be overlooked (Chukwumerije and Schroeder, 2009). 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, and trade-offs with other priorities – may also limit the smooth mainstreaming of climate adaptation action into development (Agrawala and van Aalst, 2008; Bizikova et al., 2007; Eakin and Lemos, 2006; Kok et al., 2008; Metz and Kok, 2008). 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 increased availability of irrigation canals and dams can negatively affect the incidence of malaria and water-borne diseases, 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 (Agrawal, 2008; Eakin, 2005; Wilbanks and Kates, 2010). 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, Shukla, and Kapshe, 2007; Kok et al., 2008), although in some regions (e.g., in Africa) special climate-oriented bureaus are being placed strategically in the offices of government leaders. For instance, in Kenya and Tanzania climate change coordination units have been created in high-level scales of government. These institutional arrangements constitute a growing realization of the strategic place that climate change issues occupy in some countries in Africa. The growing importance of climatic change in shaping social and governmental policy agendas has resulted in many examples of specific interventions to respond to climate change both in developed and developing regions (Ayers and Huq, 2009; Burch, 2010; Dang, Michaelowa, and Tuan, 2003), for reasons that appear to vary widely.

20.2.3. Climate-Resilient Pathways

20.2.3.1. Framing Climate-Resilient Pathways

Climate-resilient pathways connect climate change consequences with development pathways (see IPCC Working Group III: Chapter 4). They are evolutionary processes for managing change within complex systems. Pathways follow a direction; this may be toward unintended consequences of previous actions (e.g., global temperature increases of 2°C or more) or toward intended goals or visions (e.g., sustainable development). Unintended consequences are common in complex systems, where feedbacks, teleconnections, cross-scale linkages, and thresholds, and nonlinearities can result in non-linear effects that were not anticipated (Folke et al., 2002; Scheffer et al., 2009; Lenton, 2011a). Climate-resilient pathways reflect an intended goal that takes into account the knowledge that increasing atmospheric concentrations of greenhouse gas will have long-term implications for sustainable development (IPCC Working Group I). Reflecting evolutionary uncertainties, they are rooted in iterative responses that involve identifying vulnerabilities to climate change impacts; assessing opportunities for reducing risks; and taking actions that are consistent with the goals of sustainable development.

The pursuit of climate-resilient pathways may involve a combination of incremental changes 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 SREX, 2012). Given the non-linear 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). This may require transformational adaptations, i.e., responses that change the nature, composition, and/or location of threatened systems in order to maintain the potential for sustainable development (Smit and Wandel, 2006; Stringer et al., 2009; NRC, 2010a; Pelling, 2010; IPCC SREX, 2012: see section 20.5).

Climate resilient pathways call for decisions and actions that take into account both short- and long-term time horizons. Near-term responses may emphasize climate change mitigation and relatively low-cost adaptations that present development co-benefits (Van Aalst, Cannon, and Burton, 2008; NRC, 2010a). Anticipating long-term responses calls for monitoring emerging impacts and risks combined with adaptive management, learning, leadership and contingency planning (NRC, 2010a; IPCC SREX, 2012).

20.2.3.2. Elements of Climate-Resilient Pathways

As climate change continues on its current path toward relatively significant impacts (NRC, 2010b), climate-resilient pathways will become increasingly challenging, requiring explicit attention to responses in virtually all regions, sectors, and systems in order to avoid disruptions of development processes. Climate-resilient pathways include two overarching attributes: (1) actions in order to reduce climate change and its impacts, including both mitigation and adaptation, and (2) actions to assure 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 20-5 lists 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 is likely to 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, Lemos, and Boyd, 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, there may be stages of slow development followed by periods where progress increases speed. Further, the nonlinearity or randomness of climate impacts necessitates a system that allows for the flexibility to adapt to unexpected and even extreme events (Hollings, 1973). This is especially true in light of political, economic or resource constraints, where pathways at the local level will need to not only be 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 others, 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 SREX, 2012: Chapter 7).

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Box 20-5. Elements of Climate-Resilient Pathways for Sustainable Development

Awareness and capacity
- A high level of social awareness of climate change risks
- A demonstrated commitment to contribute appropriately to reducing global net GHG 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 and services
- 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, institutionalized vulnerability assessments and risk management strategy development and refinement based on emerging information and experience
- Monitoring of emerging climate change effects and contingency planning for possible significant impacts and 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

_____ END BOX 20-5 HERE _____

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 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 to 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" (Box 20-6).

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Box 20-6. Considering Geoengineering Responses

To the extent that climate change mitigation is not fully successful in moderating the rate of increase in GHG emissions, and if climate change adaptation is not successful in coping with the resulting impacts without socially unacceptable pain and distress, policymakers may be faced with demands to find further ways to reduce climate change and its effects.

Such options include expansions of mitigation and/or adaptation to include geoengineering: intentional large-scale interventions in the earth system either to reduce the sun's radiation that reaches the surface of the earth or to increase the uptake of carbon dioxide from the atmosphere. An example of the former is to inject sulfates into the stratosphere. Examples of the latter include facilities to scrub carbon dioxide from the air and chemical interventions to increase uptakes by oceans, soil, or biomass (UK Royal Society, 2009; IPCC Working Group III: Chapter 6).

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, 2009; Keith, 2000). Many of the possible options are known to be technically feasible, but their side-effects are exceedingly poorly understood (NRC, 2010b; MacCracken, 2011; Vaughan and Linten, 2011). For example, interventions in the atmosphere might not be unacceptably expensive, but they might affect the behavior of such earth system processes as the Asian monsoons (Robock et al., 2008; Brovkin et al., 2009). Interventions to increase uptakes, such as scrubbing carbon dioxide 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 (Barrett, 2008).

In any case, implications for sustainable development are largely unknown. Even though some advocates argue that geoengineering is needed now in order to avoid irreversible impact such as the loss of ocean corals, the more general view is that this is a research priority rather than current decision-making option (NRC, 2010b). The challenge is to understand what geoengineering options would do to moderate global climate change – and also to understand what their ancillary effects might be – so that, if policymakers find some decades from now that social responses to climate change have not been sufficient to avoid severe disruptions and, as a result, there is a need to consider rather dramatic technology alternatives, our understanding of potential costs and benefits for sustainable development is far better than it is now. 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 (e.g., Blackstock and Long, 2010).

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20.3.1. Mitigation

In IPCC's assessment reports, mitigation is the subject of Working Group III, to which the reader is 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 mitigation relates to sustainable development, which was addressed by Chapter 12 of Working Group III's Fourth Assessment Report (IPCC 2007) and is also the focus of Chapter 4 of its Fifth Assessment Report, including attention of 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 climate extremes and extreme events (IPCC SREX, 2012). For example, in 2009 many smaller developing nations argued at UNFCCC COP 15 that stabilizing the global atmospheric concentration of carbon dioxide at 450 parts per million (ppm), projected to result in approximately a 2^{o}C increase in global mean temperature, would lead to unacceptable impacts on their prospects for sustainable development. Although the 450 ppm target appeared to be favored by many larger countries, some low-lying island nations would cease to exist in the face of the eventual sea-level rise that could result from that temperature increase. For these countries, any concentration level above 350 ppm (projected to result in approximately a 1.5^{o}C increase) was considered unacceptable given the risks (Liverman and Billett, 2010). In this sense, mitigation is a critically important part of climate change risk management (Washington et al., 2009; Lenton, 2011b; Peters et al., 2013). Second, trajectories for technological and institutional change in order to reduce net GHG emissions interact with development pathways. In some cases, strategies to promote low-carbon growth (e.g., Table 20-2) may be congruent with sustainable development in urban settings, such as green growth strategies that reduce local and regional air pollution, enhancing prospects for multi-level governance and integrated management of resources, and encouraging broader participation in development processes (Seto et al., 2010; Lebel, 2005). 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 SRREN, 2012: 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 need to be combined with technology transitions without disrupting the development process. For example, such strategies as increasing carbon uptakes in the soil through better agricultural management practices – which can reduce net emissions – can improve soil water storage capacity and also reduce the workload of women, and practices such as conservation tillage can also increase water retention in drought conditions and help to sequester carbon in soils (Halsnaes et al., 2008)**.**

However, mitigation and development also interact in a third way in that different groups and countries' ability to implement mitigation critically depends on their 'mitigative capacity' (Yohe, 2001): their "ability to reduce anthropogenic greenhouse gas emissions or enhance natural sinks" or 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' level 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 (see Box 20-3).

[INSERT TABLE 20-2 HERE
Table 20-1: Examples of national plans for low carbon growth (Araya, 2010).

20.3.2. Adaptation

Adaptation is the subject of four chapters of this Working Group II Fifth Assessment Report (14-17), to which the reader is 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, adaptation is linked to sustainable development in several ways. First, the ability of individuals, communities and governance systems to adapt to climate change impact is predicated on a number of capacities that enable the design and implementation of different types of intervention to prepare and respond to climate impact (Wilbanks et al., 2007). Globally and nationally, many of these determinants of adaptive capacity (e.g. human capital, information and technology, material resources and infrastructure, organization and social capital, political capital, wealth and financial capital, institutions and entitlements) (Smit and Pilifozofa, 2001; Yohe and Tol, 2002; Eakin and Lemos, 2006) significantly overlap with indicators of development. However, building these capacities both in developed and less developed regions has implications to sustainable development in terms of increasing the consumption of materials and potential negative effects on ecosystems (e.g. building of new infrastructure and increasing consumption).

Second, 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 on the environment, especially in less developed regions (see section 20.40.3). 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 (Gupta et al., 2010; Nelson et al., 2007). It is also vital to understand how different capacities influence each other (positively and negatively) (Lemos et al., forthcoming) and how they may affect the long-term resilience of social-ecological systems (Adger et al., 2011; Box 20-5 illustrates the relationship between building technology and infrastructure capacities and long-term resilience and sustainability of agricultural social-ecological systems in China). Indeed, adaptation can be vitally 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 discussions regarding different adaptation options, it can encourage communities to think more clearly about broader sustainable development goals and pathways (NRC, 2010a).

Third, 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, Konrad, and Thum, 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, Travis, and Wilbanks, 2012; Park et al,, 2012; Marshall et al., 2012). Desirable adaptation strategies may vary according to climate change threat, location, impacted system, the geographical scale of attention, and the time frame of strategic risk management planning (Heltberg, Siegel, and Jorgensen, 2009; Thomalla et al., 2006; NRC, 2010a). It is important that transformational adaptation policy at different scales takes into consideration the goals of sustainable development both by fostering positive synergies and by avoiding negative feedbacks between them, especially because some adaptation options might lead to inequitable and unsustainable outcomes (Thomas and Twyman, 2005; Eriksen et al., 2011; Eriksen and Brown, 2011) (for a more detailed discussion see sections 20.3.3 and 20.4.4). Moreover, adaptation at one scale may negatively affect vulnerability in another. For example, in Vietnam, policies for forestry protection and the construction of electric dams while benefiting low land areas (by regulating flooding) have critically constrained the access to land and forest products to mountain populations, decreasing their adaptive capacity (Beckman, 2011).

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. However, creating the conditions for the emergence of such outcomes will require better integration between the goals of adaptation and sustainable development at all scales. By selecting environmentally friendly materials; promoting energy, water and other resource conservation; promoting re-use and recycling; minimizing waste generation; protecting habitat and addressing needs of marginalized groups (Bizikova et al., 2007; Seto et al., 2010), adaptation can contribute to win-win or even triple win options that can support a diverse array of development goals (see section 20.3.3).

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

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; Asian Development Bank, 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 (Halsnaes et al., 2008; Wilson and McDaniels, 2007; Ayers and Huq, 2009; Beg et al., 2002). Wilson and McDaniels (345) 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 other contexts; and (3) the *choice among alternatives* in one context can be a means for achieving the underlying values important in the other contexts.

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 -- e.g., mitigation benefits more global, adaptation benefits 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, the direct responsibility 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 is most likely to come into focus in place-based discussions of climate change responses and development objectives such as localities and small regions (Wilbanks, 2003; Bulkeley and Schroeder, 2012). Globally, a particular hurdle is applying available mitigation resources only for reducing emissions beyond that which would have occurred without those resources ("*additionality*") while recognizing that 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 (NRC, 2010a; also see section 20.4.1).

Choices in integrating adaptation and mitigation will vary according to the circumstances of each locality (de Boer et al., 2010). In the more 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 loss and damage in some industrialized countries related to climatic variability and extremes between 2010 and 2012 challenge this perception (e.g., Hurricane Sandy, tornadoes, and drought in the US 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.

As indicated above, one emerging strategy to integrate between climate and development policies is the design of "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 (2007) 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 - e.g. in national institutions and in international negotiations, and (5) *mainstreaming* adaptation and mitigation considerations into broader sustainable development policies. 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 (Barker, 2008; Swart et al., 2003); and in many cases interventions have not delivered win-win results because tradeoffs were not avoided (Warner, van der Geest, et al., 2012).

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 mitigation and adaptation pathways might be alternatives in reducing costs, complementary and reinforcing to 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). 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, 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 (Klein, Schipper, and Desai, 2005; Tol, 2004; 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 (for example interactions among options and paybacks (NRC, 2010a; Kok et al., 2008; Wilbanks and Sathaye, 2007; Swart and Raes, 2007; Rosenzweig and Tubiello, 2007; IPCC, 2007: Chapter 18). Current research is examining tradeoffs 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 how the production of biofuels might affect local adaptation (La Rovere, Avzaradel, and Monteiro, 2009); agriculture and water (Rounsevell et al., 2010; Turner et al., 2010; Rosenzweig and Tubiello, 2007; Falloon and Betts, 2010; Shah, 2009); 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, Swart, and van der Knaap, 2009; Hamin and Gurran, 2009; Roy, 2009; Romero-Lankao et al., 2011).

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 tradeoffs among economic and environmental goals (e.g., Bamuri and Opeschoor, 2007), assuring effective institutions in developing, implementing, and sustaining resilient strategies, and enhancing the range of choices through innovation (e.g., Hallegatte, 2009; Chuku, 2009; Folke et al., 2002).

20.4.1. Resolving Tradeoffs 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 tradeoffs among social, economic, and environmental goals – a central tenet of sustainable development (section 20.2.1.1).

There is a longstanding 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, 2011). Obviously, 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 s host of tradeoffs (Boyd et al., 2008), with both values and processes varying according to development context.

Examples of frameworks of thought often related to addressing tradeoffs are multi-metric valuation and co-benefits (see also Ness et al., 2007, regarding tools for sustainability assessment, and Pew Center, 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., Rose, 2010) and the construction of multi-metric indexes (e.g., an index of "biotic integrity": Johnston et al., 2011). More commonly in collective decision-making, however, analytical-deliberative group processes are used to evaluate, weight, and combine different dimensions and metrics qualitatively (NRC, 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 historically 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 which 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; also see http://www.kyomecha.org/cobene/e/cobene.html and IPCC Working Group III: Chapter 6). For example, mechanisms such as REDD are designed to achieve both carbon emissions reduction and to benefit livelihoods of those living in forested areas. However, empirical research shows that the evidence of the correlation between carbon storage and livelihoods benefits is mixed (Chhartre and Agrawal, 2009). Tools for analyzing such issues are associated with research on "externalities" (e.g., Baumol and Oates, 1989), but participative planning and decision-making usually incorporate a co-benefits perspective as a matter of course.

In practice, tradeoff issues may or not be resolved in coherent ways (Metz, 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. In some cases, tradeoffs are addressed with the assistance of scenario development, the creation of descriptive narratives, and other projections of future contingencies (IPCC SREX: Chapter 8), along with participative vulnerability assessments (NRC, 2010a).

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

Climate resilience will benefit from institutions that are effective and flexible in the face of a wider range of challenges for problem-solving and issue resolution as well. "Institutions" refer not only to formal structures and processes but also to the rules of the game as well as the norms and cultures that underpin environmental values and belief systems. 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 largely shaped by institutional values, cultures and norms. Institutions also critically define our ability to govern and manage the resources and systems that shape adaptation, mitigation and sustainable development. Adopting an adaptation and mitigation pathway requires strong institutions that are able to foster an enabling environment through which adaptive and mitigative capacities can be built (Gupta et al., 2010; IPCC, 2007: Chapter 20). 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 provides incentives and benefits that equitably distributes resources across social groups (Denton, forthcoming; McSweeny and Coomes, 2011). Hence, the trajectory to a resilient pathway needs an institutional leap, one that knowingly set rules, seeks to innovate, monitor and evaluate strategies for managing climate impacts.

Transformative action and change in integrating sustainable development within a framework of climate resilient pathways is in fact rooted in strong and viable institutions and within an institutional context that adaptively manages the allocation of resources and processes of change. Institutions at different levels have been 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). Organizational mechanisms are central to building linkages between local level adaptation action and national level planning; however, in six cases studies in West Africa and Latin America, Agrawal et al. (2011)

found that while these connections are missing in almost all the countries studied, external policy support can catalyze adaptation action through three types of intervention mechanisms– information, incentives, and institutions.

Institutions for integrated climate-resilient pathways are therefore not limited to governmental institutions; in fact, in many cases a majority of the key decisions are made and implemented by non-governmental actors, from the private sector to communities and families. For instance, in projects supported by the IDRC/DflD Climate Change Adaptation in Africa Programme (CCAA), in both Tanzania and Morocco, local governments are providing improved seeds that are drought resistant to vulnerable groups and financially supporting initiatives at community level (Denton, forthcoming). Embarking on a climate resilient pathway may necessitate including local institutions as part of the governance regime. Similarly, as local communities become more exposed to climate extremes and variability, they are already adapting to the negative impacts of climate variability and change. However, a sustainable route depends largely on the organisational capacity of vulnerable groups and their ability to translate challenges into opportunities. For example, in Morocco, where local communities have strong institutions, such as in the Tabant mountain community, they were found to be adapting collectively; but where institutions were less effective and weak, as in the arid plain of Lamzoudia, adaptation action was characterised by individual initiatives (Denton, forthcoming)

In particular, local institutions crucially influence the ability of communities to adapt and benefit from adaptation and mitigation programs in rural and urban settings (Agrawal, 2008; Chhartre and Agrawal, 2009; Corbera and Brown, 2008). 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, 2008). In rural areas, current socioeconomic dynamics, rapid population growth, commercialized agriculture, new agricultural trends and technological advancements in agriculture have meant that local institutions have seen a change in their role in governing environmental management in adaptive governance. 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 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 ensure maximum effectiveness (Ziervogel and Opere, 2010). In addition, 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. Scholars have found that deliberative processes of democracy provide greater efficacy in decision-making and lead to more sustainable outcomes. They argue that some deliberative democracy methods can bring diverse stakeholders together- lay, expert and indigenous knowledge - thus putting in place a more communicative model of science (Benn, Dunphy, and Martin, 2009), although stakeholder participation does not always lead to consensus (Rowe and Frewer, 2004).

In addition, institutions are also 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 institutions that are able to facilitate the enhancement of adaptive capacity and 'allow society to modify its institutions at a rate commensurate with the rapid rate of environmental change' (Gupta et al., 2008). Institutional 'renewal' is essential to achieve a degree of social cohesion and transformation. A case study in Morocco, under the Climate Change Adaptation in Africa (CCAA), showed that the `Cellule de Littoral`, created to serve as a consultative committee on coastal development in Morocco, has gained some recognition at both local and national levels as it is integrated formally into the institutional framework for the implementation of Integrated Coastal Zone Management Plans of Action (Denton, forthcoming).

An institutional response to climate change is even more fundamental in common pool property resources especially in river basin management. River basins are considered as public goods. However, in a changing climate many river basins are subjected to increased precipitation or water scarcity that is affecting both marine life as well as livelihoods structures of the most vulnerable. A climate resilient pathway is one that will not only manage biophysical changes, but address inherent institutional asymmetries that can further reinforce current inequalities in the way common pool resources are managed.

The quality and performance of institutions are largely predetermined by the rules they follow and the suitability of these rules based on the biophysical and social setting. In addition, the evaluative mechanism in place as checks and balances and the players within the institutions and their receptiveness to follow the rules are all necessary preconditions for climate resilient pathway. For example, the monitoring capacity of the institution/s, as well as mediation capacity and the degree to which these are embedded at different scales across the governance regime will largely determine its adaptive capacity and sustainability. Thus, the vulnerability of large river basins will largely depend on the changing biophysical conditions, but also on institutional architecture that is put in place to manage risks and build resilience. For instance, Schlager et al 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. Building resilience to climate change impacts are largely predetermined by the flexibility of the institutions to change the rules according to the changing biophysical and social setting. For instance, states such as Colorado in the United States, 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, E. and Heikkila, 2011).

It is, however, important to note that institutional arrangements are not the only determining factor in bringing about transformational change. For instance, Agrawal et al. argues that there is a strong likelihood that technological improvements and institutional arrangements can positively affect the causal relationship between ecological sustainability and social equity (also see Agrawal and Benson, 2011).
Common problems with institutional roles include a frequent incompatibility of current governance structures with many of those that may be necessary for promoting social and ecological resilience' and the fact that 'adaptive ecosystem management overturns some major tenets of traditional management styles which have in many cases operated through exclusion of users and the top-down application of scientific knowledge in rigid programmes' (Tompkins and Adger, 2004: 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 (also see IPCC Working Group III: 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 (NRC, 2010a; Lebel, 2005). 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 (IPCC SREX, 2012; Kemp, 1994; Perez, 2002).

Effective use of innovations depends on more than idea and/or technology development alone. Unless the options, 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 SREX, 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; NRC, 1999; International Council for Science, 2002; and 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 knowledge with local 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).

20.5. Determinants of Resilience in the Face of Serious Threats

Climate change is not the only threat facing societies in the 21st century; many households, communities and regions are addressing poverty, inequality, and a confluence of economic, demographic, social and cultural changes. As discussed in Chapter 13, future impacts of climate change and extreme events can slow down the pace of poverty reduction in urban areas, further erode food security, and jeopardize sustainable development. IPCC's Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC SREX, 2012) concluded that – due to climate change – climate extremes and extreme events will pose increasing challenges for natural and human systems. Successful responses to climate change will involve both incremental and transformational adaptations, with the latter dependent upon the timing and ambition levels of global greenhouse gas mitigation efforts, as well as on the choice of development pathways (Rogelj et al., 2013; Peters et al., 2013; Box 20-3).

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

Climate-resilient pathways recognize a wide range of stressors and threats, including those linked to economic, political, social and technological changes. The complexity of these non-linear, interacting changes introduces both uncertainty and surprises. Resilience is a concept that that takes into account how a system, community, or individual can deal with disturbance, uncertainty and surprise over time (Folke et al., 2010; Walker and Salt, 2006). It can be defined as the ability of a social, ecological, or socio-ecological system and its components to anticipate, prevent, reduce, accommodate, adapt or recover from the effects of a hazardous event in a timely and effective manner (see Glossary). Anticipation focuses on real or imagined changes that are different from the present situation or status quo. Scenario development, storylines, and other anticipatory systems can be used to identify potential future outcomes based on an analysis of systemic, interacting changes (Miller, 2007; van Vuuren et al., 2012; Kriegler et al., 2012; IPCC SREX, 2012: Ch8). Prevention considers the social, economic, cultural, and political costs of anticipated futures and addresses them within an ethical framework (Gardiner 2004; Warner, van der Geest, et al., 2012). It is a conservative action that is dependent upon risk analysis frameworks (See Chapter 1, Chapter 2), as well as on understandings of the barriers and limits to adaptation (see Chapter 16).

In the absence of prevention, resilience involves reducing, accommodating, adapting to or recovering from the outcomes of climate change. For example, current strategies to reduce vulnerability to increased flooding involve new ways of accommodating water in landscapes (Delta Commission, 2008), and new types of adaptations to changes in the frequency and magnitude of floods (Environment Agency, 2009; Milly et al., 2008). The distinction between incremental adaptation and transformational adaptation is significant: Incremental adaptation can be considered extensions of actions and behaviors that already reduce losses or enhance benefits associated with climate change, often where the goal is to maintain the essence and integrity of an incumbent 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 greater scale or 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). There is growing evidence that climate change is going to be significant enough for many locations and systems that climate-resilient pathways will have to consider transformational change in advance of disruptive impacts in order to reduce risk and vulnerability (see Chapters 14-17). Transformational adaptation often occurs in continuous interaction with incremental adaptations (Park et al., 2012, see IPCC SREX, 2012, Figure 8-1). However, the rate and magnitude of climate change can influence the resilience of the system, in some cases undermining the capacity to adapt to change, and introduce limits to adaptation (Adger et al., 2009; Marshall et al., 2012).

Estimates of loss and damages associated with climate variability and change over time suggest that the rate and magnitude of climate change has significance for sustainable development (IPCC SREX, 2012; Beddoe et al., 2009; Warner, van der Geest, et al., 2012). The severity of climate change is influenced by the rate and timing of greenhouse gas emissions (Kriegler et al., 2012). Model results based on integrated scenarios that take into account geophysical, technological, social and political uncertainties indicate that achieving the often-discussed 2°C average global temperature increase calls for mitigation of emissions through increased energy efficiency and lower energy demand well before 2020 (Rogelj et al., 2013; Peters et al., 2013; section 20.6.1). In the absence of ambitious mitigation efforts, the future impacts of climate change can be expected to be non-linear, with the potential for crossing thresholds and tipping points (Lenton, 2011a). 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. Indicators of critical transitions include an increase in recovery times from disturbances, and changes in spatial patterns (Scheffer et al., 2009).

Because of the large negative impacts of crossing climate tipping points, such scenarios are important to include in risk assessments and response strategies. An analysis of historical collapses of ancient states or civilizations indicates that transformations at a large social or spatial scale are associated with multi-causality with cascading feedbacks, and that collapses can be avoided by through collective strategies that contribute to socio-ecological resilience (Butzer and Endfield, 2012; Butzer, 2012; Dugmore et al., 2012). Such resilience calls not only for adaptability, but also for transformability (Folke et al., 2010; Westley et al., 2011). Consequently, in addition to transformational adaptation and transformations to low-carbon societies, there is increased attention to the importance of transformations for global sustainability, which in many cases include social transformations (Folke et al., 2009; Pelling, 2010; Westley et al., 2011).

20.5.2. Elements of and Potentials for Transformational Change

Given the risks of climate change and associated impacts on natural and managed resources and systems, human settlements, industry, infrastructure, health, well-being, and human security, and given the limits to adaptation discussed in Chapter 16, there are increasing calls for deliberate transformations towards global sustainability (Raskin et al., 2002; WBGU, 2011; Westley et al., 2011; O'Brien, 2012). Global sustainability includes the goals of sustainable development, but considers them within the context of planetary and social boundaries (Rockström et al., 2009; Leach et al., 2012). Transformation is defined as a change in the fundamental attributes of a system, often based on altered paradigms, goals, or values. Transformations can occur in technological or biological systems, financial structures, and regulatory, legislative, or administrative regimes (see glossary). Transformation in wider political, economic and social systems can either open up or close policy spaces for more resilient and sustainable forms of climate responses, particularly where contemporary development pathways are identified and addressed as part of the root causes of vulnerability (Pelling, 2010; IPCC SREX, 2012: Chapter 8).

There is an extensive literature on transitions and transformations, covering a variety of sectors and factors that influence changes in systems and behaviors (Calvin et al., 2009; Berkhout et al., 2010; Shove and Walker, 2010; Pelling 2010; Geels, 2002; IPCC Working Group III: Chapter 6). Transformation can be triggered by events, but often they are long-term processes (Loorbach, 2007). Factors that may improve prospects for both initiating and sustaining transformations can include dramatic focal events that catalyse attention to vulnerabilities; the presence of other sources of stress that also encourage considerations of major changes; and supportive social contexts such as the availability of understandable and socially acceptable options, access to resources for action, and the presence of incentives. Transformation is also linked to adaptive leadership, empowerment and collaboration within and across institutions, organizations and groups (IPCC SREX, 2012: Chapter 8; Heifetz et al., 2010; Kates et al., 2012; Moser

2013). 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 perspectives (Loorbach 2007; Folke et al., 2010; Westley et al., 2011; Schlitz et al., 2010). Many of the elements of climate resilient pathways discussed in Box 20-5 can, in fact, support transformation.

While transformations may be reactive, forced or induced by random, stochastic factors, they may also be deliberately created (Folke et al., 2010; O'Brien, 2012; Kates et al., 2012). Deliberate transformations can take place across interacting spheres, referred to by O'Brien and Sygna (forthcoming) as the practical, political and personal spheres of transformation (see Figure 20-2). The practical sphere includes social and technological innovations, behavioral changes, and institutional and managerial reforms that directly influence outcomes. Although this is where most attention is currently focused, transformations in this sphere are challenging because they seldom question or address larger systems and structures. Consequently, the lines between business-as-usual and transformation in this sphere are easily blurred. The political sphere represents the economic, political, legal, social and cultural systems that define the boundaries within which practical transformations take place. It is within this sphere where problems and solutions are identified and defined, and where value conflicts are often experienced and resolved. The political sphere is often a reflection of dominant cultural beliefs and worldviews that are seldom recognized or questioned. These involve transformations in the personal sphere, which includes individual and collective beliefs, values and worldviews that shape the ways that systems and structures are viewed, as well as the practical solutions that are considered possible. Transformations in this sphere often represent paradigm shifts that can influence both political and practical interventions. Whether in relation to transformational adaptation, transformation to low-carbon societies, or transformations to global sustainability, attention to all three spheres is considered necessary in response to the observed and anticipated impacts of climate change (Beddoe et al., 2009). As discussed in the next section, climate resilient pathways may involve conflicting goals and visions for the future, and not every transformation is considered equally ethical, equitable or sustainable. The normative dimension of climate change responses and climate resilient pathways is thus an important part of both discussions and actions related to sustainable development.

[INSERT FIGURE 20-2 HERE
Figure 20-2: The three spheres of transformation.]

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 multiple paths leading to the same total amount of climate resilience: alternative stable states (Hollings, 1973). At any time period along a pathway, more or less resilience maybe 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: a) foresee risk/vulnerability, b) decrease climate change impacts, c) respond rapidly to unpredictable, uneven and extreme events, d) include considerable amounts of proactive adaptation, and e) evolve in support of societal advancement and balanced environmental management.

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 alterative climate resilient pathways.

In the event that global surface mean temperatures rise through +2ºC to +4ºC and higher (Schneider, 2009; New et al., 2012; Anderson and Bows, 2008), sustainability will become significantly more difficult to achieve (food security is a notable example: 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, GHGs 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 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, potential for economic development and growth, ecological and ecosystem services, access to natural resources, institutional and governance structures, and technological development and transfer. The concept of Shared Socioeconomic Pathways (SSPs) at the global level offers one framework for considering alternative mixes of actions in support of climate resilience (Box 20-3). SSPs consider alternative socioeconomic pathways according to dimensions related to both the resource intensity of economic growth and the effectiveness of institutions in resolving tradeoffs (Kriegler, et al., 2012). Five notional pathways have been developed to illustrate a range or possible futures, as a basis for discussion, with each SSP following a distinct storyline (Figure 20-3). These dimensions can then be related to socioeconomic challenges confronting climate change mitigation and adaptation (as one aspect of sustainable development). In Figure 20-3, Pathway 1 has relatively limited challenges to both adaptation and mitigation, while Pathway 3 has substantial challenges to both adaptation and mitigation. Any pathway characterised by low challenges to both is likely to be climate- resilient at the global scale and in many local or national situations. A pathway characterised by high challenges to both adaptation and mitigation is less likely to be climate-resilient at the global scale and in many localities and countries.

[INSERT FIGURE 20-3 HERE
Figure 20-3: A notional depiction of alternative climate-resilient sustainable development pathways (lower left). Regarding SSPs, see Box 20-3; SSPs are representations of alternative socioeconomic pathways within which climate change responses might evolve.]

Considering alternative climate-resilient pathways cannot be separated from levels of climate change. In principle, most climate change scientists, decision-makers, and stakeholders agree that: (a) 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; (b) 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 (c) 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 degrees C would mean impacts that are incompatible with sustainable development (Metz et al., 2002**).** IPCC's Fourth Assessment Report concluded that there is an approximate threshold, between 2.5 and 3 degrees C of warming, above which impact concerns are severe but below which concerns are less severe (IPCC, 2007). Other scientists are unconvinced that system sensitivities to climate parameters such as temperature increase are well-enough understood to support any specific warming threshold (e.g., NRC, 2010c), and some scientists and policymakers are unconvinced that 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).

20.6.2. Implications for Current Sustainable Development Strategies and Choices

Although payoffs from specific long-term pathways may be uncertain at this time, such uncertainties need not preclude actions now. Climate-resilient development pathways are not about actions taken in the future, but rather about the strategies and choices that are taken today. The range of potential climate outcomes, discussed in Box 20-3, will have dramatically different implications for human security, as well as for the health and status of species and ecosystems (IPCC WGII, AR5). Increasingly, the literature linking climate change to greenhouse gas concentrations shows that the emissions in the coming decades will be decisive for future climate outcomes (Anderson and Bows, 2008; Meinshausen et al., 2009; Solomon et al., 2009).

In fact, waiting to take action may reduce the range of choices for climate resilient pathways in the future (NRC, 2011b). The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), 2012, makes the case that a "solution space" 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. The solution space emphasizes the linkages between different strategies, recognizing that no single approach alone is likely to be sufficient.

Meanwhile, in some parts of the world, current failures to address effects of emerging climate stressors are already leading toward adaptation strategies that erode bases for sustainable development 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 are clearly non-sustainable (Warner and Afifi 2012a; Warner, van der Geest, et al., 2012).

In discussing approaches to sustainability in the context of climate extremes, the SREX report draws attention not only to the role of incremental change, but also to transformation, which is defined as "the altering of fundamental attributes of a system (including value systems; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biological systems) (IPCC SREX, p. 564). Climate-resilient development pathways that deliberately address mitigation and adaptation through both incremental and transformative strategies are likely to present more options for sustainable development than those pathways that reactively respond to the challenges of climate change.

20.7. Priority Research/Knowledge Gaps

Simply stated, what is known about integrating climate change mitigation, climate change adaptation, and sustainable development is dwarfed by what is not known. If national and global decision-makers wish to realize potentials from a fusion of these three imperatives, then research should be a very high priority indeed. 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; NRC, 2011). What are the major tradeoffs? 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:

1) Research on how to reconcile the importance of synergies between climate change adaptation and mitigation actions with widespread use of the concept of additionality, e.g., how to establish criteria for access to financial support for adaptation that incorporates the development importance of co-benefits. For

example, such research could inform discourses about differences between adaptation and development in ways that enable the flow of financial resources to support adaptations: e.g., how to acknowledge co-benefits in allocating investment resources without inviting every party seeking development investment to use climate change as an opportunity (NRC, 2010a).

2) 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; and possible thresholds/tipping points that could cause particular challenges for development (NRC, 2009, 2010a).
3) 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 impacted human and/or environmental systems. What might the options be, and how can they be facilitated where they should be considered? (e.g., Pelling, 2010).

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 understandings of how social institutions affect resource use (NRC, 2009), improving understandings of risk-related judgment and decision-making under uncertainty (NRC, 2009), and best practices in creating institutions that will effectively integrate climate change responses with sustainable development outcomes such as participation, equity, and accountability
- Research on strategies for the implementation of adaptive management 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: e.g., adaptive management and governance capacity, and improving the understanding of differences between retrofitting older infrastructures (the challenge in many industrialized countries) and designing new infrastructures (the challenge in many rapidly developing countries) (IPCC SREX, 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 contests (IPCC SREX, 2012: Chapter 8).
- Research on factors that influence deliberate transformations that are ethical, equitable, and sustainable (O'Brien, 2012; Kates, Travis, and Wilbanks, 2012).
- The development of structures for learning from emerging integrated climate change response/development experience: e.g., approaches and structures for monitoring, recording, evaluating, and learning from experience, identifying "best practices" and their characteristics (NRC, 2010a; IPCC SREX, 2012: Chapter 8; Hilden, 2011).

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 solutions. 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 geo-engineering costs, benefits, a wide range of possible impacts, and fair and equitable structures for global policymaking and decision-making (UK Royal Society, 2009; Kates, Travis, and Wilbanks, 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.

Frequently Asked Questions

FAQ 20.1: Why are climate-resilient pathways needed for sustainable development?
Sustainable development requires managing many threats and risks, including climate change. Because climate change can no longer be avoided and, in fact, 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.

FAQ 20.2: What is a climate-resilient pathway?
A climate-resilient pathway for development is a continuing process of change management, 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.

FAQ 20.3: Are there things that we can be doing now that will put us on the right track toward climate-resilient pathways?
Yes. We can carry out participative vulnerability assessments, look for ways to reduce vulnerabilities to effects of climate change that have other development benefits as well, monitor emerging climate changes and adaptive responses to improve our understanding of risks, and revise our vulnerability assessments and risk management strategies continually on the basis of growing evidence, knowledge, and experience. In many cases, these activities can be linked with other issues for sustainable development as well.

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Table 20-1: Effectiveness of water-saving irrigation dealing with climate change (Zou et al., 2012).

	2007	2008	2009
Water saved (Bm^3)	19.37-40.86	19.86-41.55	22.58-47.25
Energy saved (Mt)	2.92-6.39	3.08-6.72	3.58-7.73
CO_2 emission reduction (Mt)	6.66-14.58	7.02-15.31	8.15-17.59

Table 20-1: Examples of national plans for low carbon growth (Araya, 2010).

Country	Vision	Innovation
China	*Low carbon zones to provide a laboratory for large-scale low carbon private and public investment*. Europe-China collaboration to pioneer approaches compatible with Chinese institutions and development.	Low Carbon Zones build on 1980s Special Economic Zones (SEZs)
Maldives	Carbon neutrality by 2020 Climate change central development priority for government	Island with focus beyond adaptation
Mexico	Emissions peaking in 2012 and 50 percent reduction below 2000 levels by 2050 Establishment of low carbon development scenarios and priorities	2050 time horizon; peaking objectives; investment platform
South Korea	Plan to guide transition to low carbon economy 80 percent of economic stimulus package going into low carbon measures	Green recovery; public resources commitment
Japan	25% reduction in 2020 compared with 1990 level 80% reduction in 2050 compared with 1990 level Development of mid- and long-term roadmap	Mid- and long-term roadmap Subcommittee, Global Environmental Committee, Central Environmental Council

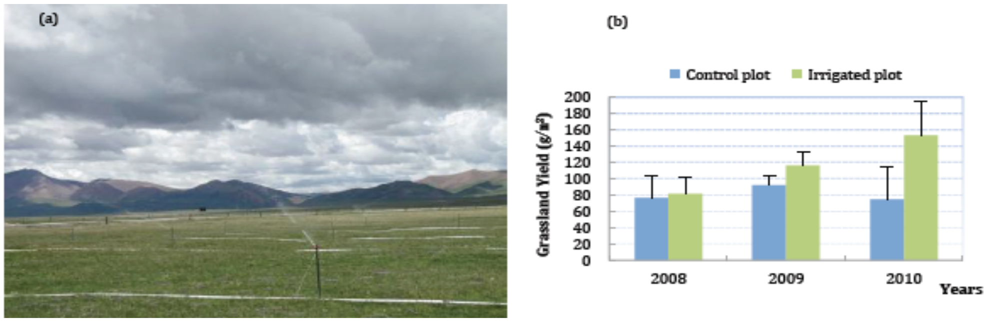

Figure 20-1: The demonstration of alpine grassland water-saving irrigation measures for adaptation to climate change in Northern Tibet.

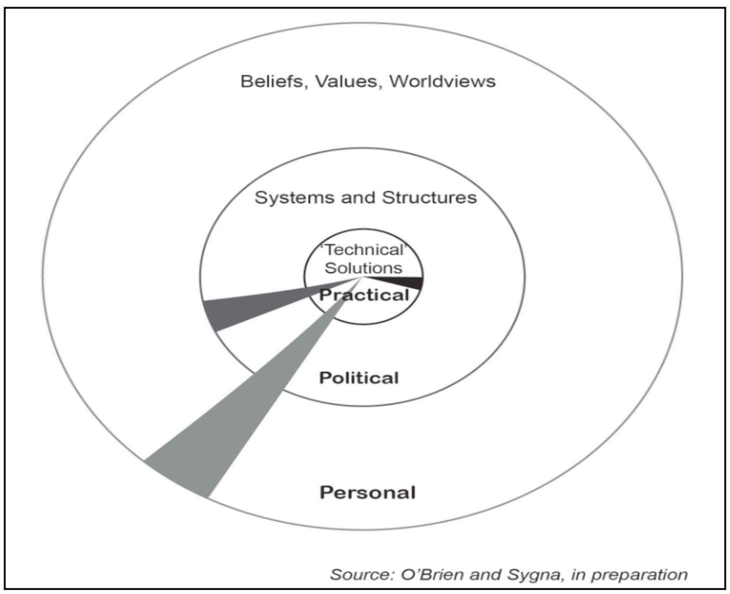

Figure 20-2: The three spheres of transformation.

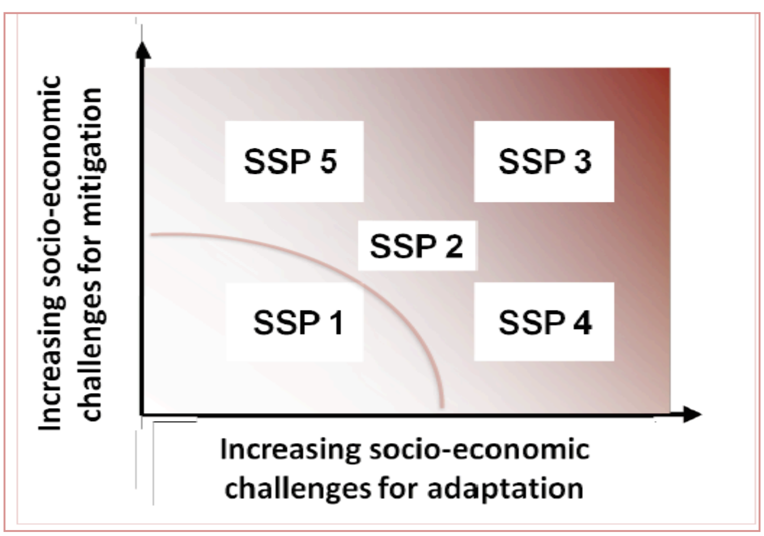

Figure 20-3: A notional depiction of alternative climate-resilient sustainable development pathways (lower left). Regarding SSPs, see Box 20-3; SSPs are representations of alternative socioeconomic pathways within which climate change responses might evolve.