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Perspectives on climate change and sustainability

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This chapter should be cited as:

Yohe, G.W., R.D. Lasco, Q.K. Ahmad, N.W. Arnell, S.J. Cohen, C. Hope, A.C. Janetos and R.T. Perez, 2007: Perspectives on climate change and sustainability. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 811-841.

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Executive summary

Vulnerability to specific impacts of climate change will be most severe when and where they are felt together with stresses from other sources [20.3, 20.4, 20.7, Chapter 17 Section 17.3.3] (very high confidence).

Non-climatic stresses can include poverty, unequal access to resources, food security, environmental degradation and risks from natural hazards [20.3, 20.4, 20.7, Chapter 17 Section 17.3.3]. Climate change itself can, in some places, produce its own set of multiple stresses; total vulnerability to climate change, *per se*, is greater than the sum of vulnerabilities to specific impacts in these cases [20.7.2].

Efforts to cope with the impacts of climate change and attempts to promote sustainable development share common goals and determinants including access to resources (including information and technology), equity in the distribution of resources, stocks of human and social capital, access to risk-sharing mechanisms and abilities of decision-support mechanisms to cope with uncertainty [20.3.2, Chapter 17 Section 17.3.3, Chapter 18 Sections 18.6 and 18.7] (very high confidence). Nonetheless, some development activities exacerbate climate-related vulnerabilities [20.8.2, 20.8.3] (very high confidence).

It is very likely that significant synergies can be exploited in bringing climate change to the development community and critical development issues to the climate-change community [20.3.3, 20.8.2, 20.8.3]. Effective communication in assessment, appraisal and action are likely to be important tools, both in participatory assessment and governance as well as in identifying productive areas for shared learning initiatives. Despite these synergies, few discussions about promoting sustainability have thus far explicitly included adapting to climate impacts, reducing hazard risks and/or promoting adaptive capacity [20.4, 20.5, 20.8.3].

Climate change will result in net costs into the future, aggregated across the globe and discounted to today; these costs will grow over time [20.6.1, 20.6.2] (very high confidence).

More than 100 estimates of the social cost of carbon are available. They run from US$-10 to US$+350 per tonne of carbon. Peer-reviewed estimates have a mean value of US$43 per tonne of carbon with a standard deviation of US$83 per tonne. Uncertainties in climate sensitivity, response lags, discount rates, the treatment of equity, the valuation of economic and non-economic impacts and the treatment of possible catastrophic losses explain much of this variation including, for example, the US$310 per tonne of carbon estimate published by Stern (2007). Other estimates of the social cost of carbon span at least three orders of magnitude, from less than US$1 per tonne of carbon to over US$1,500 per tonne [20.6.1]. It is likely that the globally-aggregated figures from integrated assessment models underestimate climate costs because they do not include significant impacts that have not yet been monetised [20.6.1, 20.6.2, 20.7.2, 20.8, Chapter 17 Section 17.2.3, Chapter 19]. It is virtually certain that aggregate estimates mask significant differences in impacts across sectors and across regions, countries and locally [20.6, 20.7, 20.8, Chapter 17 Section 17.3.3]. It is virtually certain that the real social cost of carbon and other greenhouse gases will rise over time; it is very likely that the rate of increase will be 2% to 4% per year [20.6, 20.7]. By 2080, it is likely that 1.1 to 3.2 billion people will be experiencing water scarcity (depending on scenario); 200 to 600 million, hunger; 2 to 7 million more per year, coastal flooding [20.6.2].

Reducing vulnerability to the hazards associated with current and future climate variability and extremes through specific policies and programmes, individual initiatives, participatory planning processes and other community approaches can reduce vulnerability to climate change [20.8.1, 20.8.2, Chapter 17 Sections 17.2.1, 17.2.2 and 17.2.3] (high confidence). Efforts to reduce vulnerability will be not be sufficient to eliminate all damages associated with climate change [20.5, 20.7.2, 20.7.3] (very high confidence).

Climate change will impede nations' abilities to achieve sustainable development pathways as measured, for example, by long-term progress towards the Millennium Development Goals [20.7.1] (very high confidence).

Over the next half-century, it is very likely that climate change will make it more difficult for nations to achieve the Millennium Development Goals for the middle of the century. It is very likely that climate change attributed with high confidence to anthropogenic sources, *per se*, will not be a significant extra impediment to nations reaching their 2015 Millennium Development Targets since many other obstacles with more immediate impacts stand in the way [20.7.1].

Synergies between adaptation and mitigation measures will be effective until the middle of this century (high confidence), but even a combination of aggressive mitigation and significant investment in adaptive capacity could be overwhelmed by the end of the century along a likely development scenario [20.7.3, Chapter 18 Sections 18.4, 18.7, Chapter 19] (high confidence).

Until around 2050, it is likely that global mitigation efforts designed to cap effective greenhouse gas concentrations at 550 ppm would benefit developing countries significantly, regardless of whether climate sensitivity turns out to be high or low and especially when combined with enhanced adaptation. Developed countries would also likely see significant benefits from an adaptation-mitigation intervention portfolio, especially for high climate sensitivities and in sectors and regions that are already showing signs of being vulnerable. However, by 2100, climate change will likely produce significant impacts across the globe, even if aggressive mitigation were implemented in combination with significantly enhanced adaptive capacity [20.7.3].

20.1 Introduction – setting the context

Consistent with the Bruntland Commission (WCED, 1987), the Third Assessment Report (TAR) (IPCC, 2001b) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". There are many alternative definitions, of course, and none is universally accepted. Nonetheless, they all emphasise one or more of the following critical elements: identifying what to develop, identifying what to sustain, characterising links between entities to be sustained and entities to be developed and envisioning future contexts for these links (NRC, 1999). Goals, indicators, values and practices can also frame examinations of sustainable development (Kates et al., 2005). The essence of sustainable development throughout is meeting fundamental human needs in ways that preserve the life support systems of the planet (Kates et al., 2000). Its strength lies in reconciling real and perceived conflicts between the economy and the environment and between the present and the future (NRC, 1999). Authors have emphasised the economic, ecological and human/social dimensions that are the pillars of sustainable development (Robinson and Herbert, 2001; Munasinghe et al., 2003; Kates et al., 2005). The economic dimension aims at improving human welfare (such as real income). The ecological dimension seeks to protect the integrity and resilience of ecological systems, and the social dimension focuses on enriching human relationships and attaining individual and group aspirations (Munasinghe and Swart, 2000), as well as addressing concerns related to social justice and promotion of greater societal awareness of environmental issues (O'Riordan, 2004).

The concept of sustainable development has permeated mainstream thinking over the past two decades, especially after the 1992 Earth Summit where 178 governments adopted Agenda 21 (UNDSD, 2006). Ten years later, the 2002 World Summit on Sustainable Development (WSSD, 2002) made it clear that sustainable development had become a widely-held social and political goal. Even though, as illustrated in Asia by the Institute for Global Environmental Strategies (IGES, 2005), implementation remains problematic, there is broad international agreement that development programmes should foster transitions to paths that meet human needs while preserving the Earth's life-support systems and alleviating hunger and poverty (ICSU, 2002) by integrating these three dimensions (economic, ecological and human/social) of sustainable development. Researchers and practitioners in merging fields, such as 'sustainability science' (Kates et al., 2000), multi-scale decision analysis (Adger et al., 2003) and 'sustainomics' (Munasinghe et al., 2003), seek to increase our understanding of how societies can do just that.

Climate change adds to the list of stressors that challenge our ability to achieve the ecologic, economic and social objectives that define sustainable development. Chapter 20 builds on the assessments in earlier chapters to note the potential for climate change to affect development paths themselves. Figure 20.1 locates its key topics schematically in the context of the three pillars of sustainable development. Topics shown in the centre of the triangle (the 'three-legged stool' of sustainable development) are linked with all three pillars. Other topics, placed outside the triangle, are located closer to one leg or another. The arrows leading from the centre indicate that adaptation to climate change can influence the processes that join the pillars rather than the individual pillars themselves. For example, the technical and economic aspects of renewable resource management could illustrate efforts to support sustainable development by working with the economy-ecology connection – all nested within a decision space of other global development pressures, including poverty.

Section 20.2 begins with a brief review of the current understanding of impacts and adaptive capacity as described earlier (see Chapter 17). Section 20.3 assesses impacts and adaptation in the context of multiple stresses. Section 20.4 focuses on links to environmental quality and explores the notion of adding climate-change impacts and adaptation to the list of components of environmental impact assessments. Section 20.5 addresses implications for risk, hazards and disaster management, including the challenge of reducing vulnerability to current climate variability and adapting to long-term climate change. Section 20.6 reviews global and regionally-aggregated estimates of economic impacts. Section 20.7 assesses the implications for achieving sustainable development across various time-scales. Section 20.8 considers opportunities, co-benefits and challenges for climate-change adaptation, and for linking (or mainstreaming) adaptation into national and regional development planning processes. Section 20.9 finally identifies research priorities.

This entire chapter should be read with the recognition that the first 19 chapters of this volume assess the regional and global impacts of climate change and the opportunities and challenges for adaptation. Chapters 17 and 19 in this volume offer synthetic overviews of this work that focus specifically on adaptation and key vulnerabilities. Chapter 20 in this volume expands the discussion to explore linkages with sustainable development, as do Chapters 2 and 12 in IPCC (2007a). Sustainable development was addressed in IPCC (2001b), but not in IPCC (2001a).

20.2 A synthesis of new knowledge relating to impacts and adaptation

Recent work at the intersection of impacts and adaptation has confirmed that adaptation to climate change is, to a limited extent, already happening (Chapter 17, Section 17.2). Perhaps more importantly for this chapter, recent work has also reconfirmed the utility of the prescription initially presented in Smit et al. (2001) that (1) any system's vulnerability to climate change and climate variability could be described productively in terms of *its exposure to the impacts of climate and its baseline sensitivity to those impacts* and that (2) both exposure and sensitivity can be influenced by that system's *adaptive capacity* (Chapter 17, Section 17.3.3). The list of critical determinants of adaptive capacity was described in Smit et al. (2001) and has been explored subsequently by, for example, Yohe and Tol (2002), Adger and Vincent (2004), Brenkert and Malone (2005)

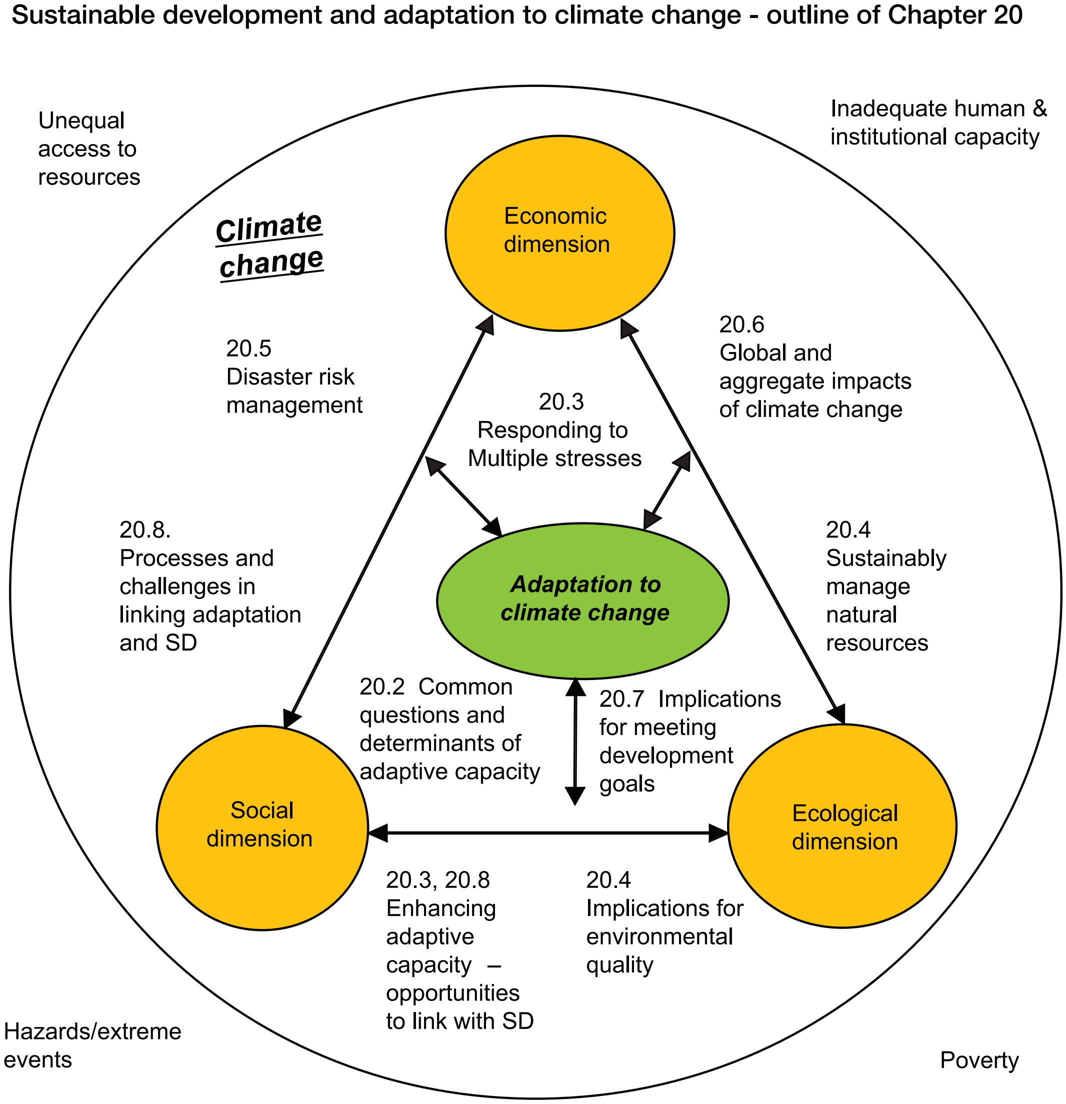


Figure 20.1. *Sustainable development and adaptation to climate change. An outline of Chapter 20 is mapped against the pillars of sustainable development. The figure is adapted from Munasinghe and Swart (2005).*

and Brooks and Adger (2005) – a list that includes access to economic and natural resources, entitlements (property rights), social networks, institutions and governance, human resources and technology (Chapter 17, Section 17.3.3).

It is, however, important to note that recent work has also emphasised the fundamental distinction between adaptive capacity and adaptation implementation. There are significant barriers to implementing adaptation (Chapter 17, Section 17.3.3) and they can arise almost anywhere. The description offered by Kates et al. (2006) of the damages and costs caused by Hurricane Katrina in New Orleans, denominated in economic and human terms, provides a seminal example of this point. Notwithstanding the widely accepted assertion that the United States has high adaptive capacity, the impacts of Hurricane Katrina were fundamentally the result of a failure of adaptive infrastructure (improperly constructed levées that led to a false sense of security) and planning (deficiencies in evacuation plans, particularly in many of the poorer sections of the cities). The capacity provided by public and private investment over the past few decades was designed to handle a hurricane like Katrina; it was the anticipatory efforts to provide protection prior to landfall and response efforts after landfall that failed.

Nothing in the recent literature has undermined a fundamental conclusion in Smit et al. (2001) that “current knowledge of adaptation and adaptive capacity is insufficient for reliable prediction of adaptations; it is also insufficient for rigorous evaluation of planned adaptation options, measures and policies of governments.” (page 880). This conclusion is often supported by noting the uneven distribution of adaptive capacity across and within societies (Chapter 17, Section 17.3.2), but strong support can also be derived from the paucity of estimates of the costs of adaptation (Chapter 17, Section 17.2.3). While many adaptations can be implemented at low costs, comprehensive estimates of costs and benefits of adaptation currently do not exist except, perhaps, for costs related to adapting to sea-level rise and changes in the temporal and spatial demand for energy (heating versus cooling). Global diversity is one problem in this regard, but there are others. Anticipating the discussion of multiple stresses that appears in the next section of this chapter, it is now understood that climate change poses novel risks that often lie outside the range of past experience (Chapter 17, Section 17.2.1) and that adaptation measures are seldom undertaken in response to climate change alone (Chapter 17, Sections 17.2.2 and 17.3.3).

20.3 Impacts and adaptation in the context of multiple stresses

20.3.1 A catalogue of multiple stresses

The current literature shows a growing appreciation of the multiple stresses that ecological and socio-economic systems face, how those stresses are likely to change over the next several decades, and what some of the net environmental consequences are likely to be. The Pilot Analysis of Global Ecosystems prepared by the World Resources Institute (WRI, 2000) conducted literature reviews to document the state and condition of forests, agro-ecosystems, freshwater ecosystems and marine systems. The Millennium Ecosystem Assessment (MA) comprehensively documented the condition and recent trends of ecosystems, the services they provide and the socio-economic context within which they occur. It also provided several scenarios of possible future conditions (MA, 2005). For reference, the MA offered some startling statistics. Cultivated systems covered 25% of Earth's terrestrial surface in 2000. On the way to achieving this coverage, global agricultural enterprises converted more area to cropland between 1950 and 1980 than in the 150 years between 1700 and 1850. As of the year 2000, 35% of the world's mangrove areas and 20% of the world's coral reefs had been lost (with another 20% having been degraded significantly). Since 1960, withdrawals from rivers and lakes have doubled, flows of biologically available nitrogen in terrestrial ecosystems have doubled, and flows of phosphorus have tripled. At least 25% of major marine fish stocks have been overfished and global fish yields have actually begun to decline. MA (2005) identified major changes in land cover, the consequences of which were explored by Foley et al. (2005).

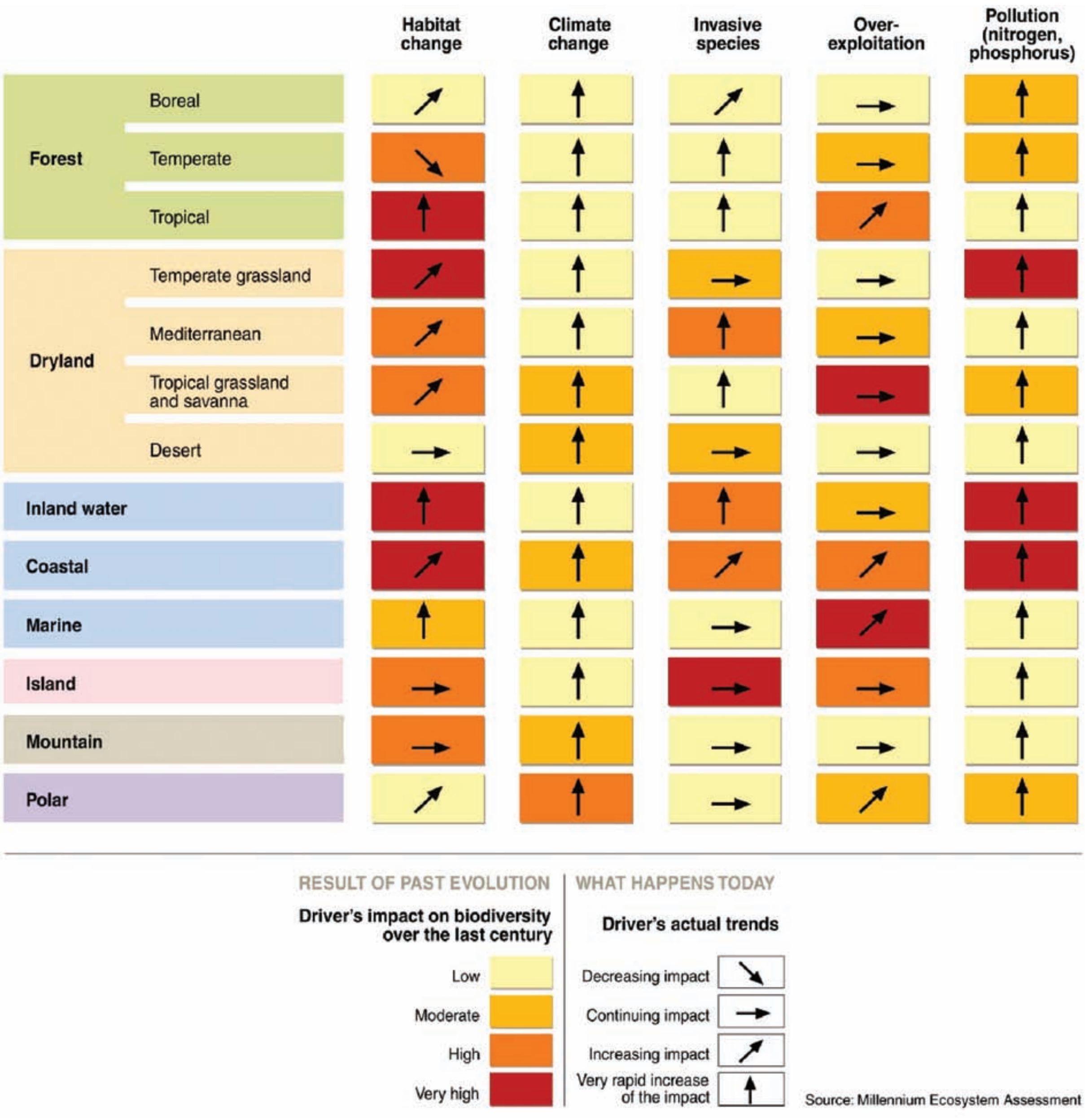
The MA (2005) recognised two different categories of drivers of change. Direct drivers of ecosystem change affect ecosystem characteristics in specific, quantifiable ways; examples include land-cover and land-use change, climate change and species introductions. Indirect drivers affect ecosystems in a more diffuse way, generally by affecting one or more direct drivers; here examples are demographic changes, socio-political changes and economic changes. Both types of drivers have changed substantially in the past few decades and will continue to do so. Among direct drivers, for example, over the past four decades, food production has increased by 150%, water use has doubled, wood harvests for pulp and paper have tripled, timber production has doubled and installed hydropower capacity has doubled. On the indirect side, global population has doubled since the 1960s to reach 6 billion people while the global economy has increased more than six fold.

Table 20.1 documents expectations for how several of the direct drivers of ecosystem change are likely to change in magnitude and importance over time. With the exception of polar regions, coastal ecosystems, some dryland systems and montane regions, climate change is not, today, a major source of stress; but climate change is the only direct driver whose magnitude and importance to a series of regions, ecosystems and resources is likely to continue to grow over the next several decades. Table 20.1 illustrates the degree to which these ecosystems are currently experiencing stresses from several direct drivers of change simultaneously. It shows that potential interactions with climate change are likely to grow over the next few decades with the magnitude of climate change itself.

20.3.2 Factors that support sustainable development

A brief excursion into some of the recent literature on economic development is sufficient to support the fundamental observation that the factors that determine a country's ability to promote (sustainable) development coincide with the factors that influence adaptive capacity relative to climate change, climate variability and climatic extremes. The underlying prerequisites for sustainability in specific contexts are highlighted in italics in the discussion which follows. The point about coincidence in underlying factors is made by matching the terms in italics with the list of determinants of adaptive capacity identified above (Chapter 17, Section 17.3.3): *access to resources, entitlements* (property rights), *institutions and governance, human resources* (human capital in the economics literature) and *technology*. They are all reflected in one or more citations from the development literature cited here, and they conform well to the "5 capital" model articulated by Porritt (2005) in terms of human, manufactured, social, natural and financial capital.

Lucas (1988) concluded early on that differences in *human capital* are large enough to explain differences between the long-run growth rates of poor and rich countries. Moretti (2004), for example, showed that businesses located in cities where the fraction of college graduates (highly *educated* work force) grew faster and experienced larger increases in productivity. Guiso et al. (2004) explored the role of *social capital* in peoples' abilities to successfully take advantage of financial structures; they found that *social capital* matters most when education levels are low and law enforcement is weak. Rozelle and Swinnen (2004) looked at transition countries in central Europe and the former Soviet Union; they observed that countries growing steadily a decade or more after economic reform had accomplished a common set of intermediate goals: achieving macroeconomic stability, *reforming property rights*, and *creating institutions to facilitate exchange*. Order and timing did not matter, but meeting all of these underlying objectives was critical. Winters et al. (2004) reviewed a wide literature on the links between trade liberalisation and poverty reduction. They concluded that a favourable relationship depends on the existence and *stability of markets*, the ability of economic actors to handle changes in risk, *access to technology, resources, competent and honest government, policies that promote conflict resolution* and *human capital accumulation*. Shortfalls in any of these underpinnings make it extremely difficult for the most disadvantaged citizens to see any advantage from trade. Finally, Sala-i-Martin et al. (2004) explained economic growth by variation in national



		Habitat change	Climate change	Invasive species	Over-exploitation	Pollution (nitrogen, phosphorus)
Forest	Boreal	⬜ ↗	⬜ ↑	⬜ ↗	⬜ →	🟨 ↑
	Temperate	🟧 ↘	⬜ ↑	⬜ ↑	🟨 →	🟨 ↑
	Tropical	🟥 ↑	⬜ ↑	⬜ ↑	🟧 ↗	⬜ ↑
Dryland	Temperate grassland	🟥 ↗	⬜ ↑	🟨 →	⬜ →	🟥 ↑
	Mediterranean	🟧 ↗	⬜ ↑	🟧 ↑	🟨 →	⬜ ↑
	Tropical grassland and savanna	🟧 ↗	🟨 ↑	⬜ ↑	🟥 →	🟨 ↑
	Desert	⬜ →	🟨 ↑	🟨 →	⬜ →	⬜ ↑
Inland water		🟥 ↑	⬜ ↑	🟧 ↑	🟨 →	🟥 ↑
Coastal		🟥 ↗	🟨 ↑	🟧 ↗	🟧 ↗	🟥 ↑
Marine		🟨 ↑	⬜ ↑	⬜ →	🟥 ↗	⬜ ↑
Island		🟧 →	⬜ ↑	🟥 →	🟧 →	⬜ ↑
Mountain		🟧 →	🟨 ↑	⬜ →	⬜ →	⬜ ↑
Polar		⬜ ↗	🟧 ↑	⬜ →	🟨 ↗	🟨 ↑

RESULT OF PAST EVOLUTION

Driver's impact on biodiversity over the last century

Low ⬜
Moderate 🟨
High 🟧
Very high 🟥

WHAT HAPPENS TODAY

Driver's actual trends

Decreasing impact ↘
Continuing impact →
Increasing impact ↗
Very rapid increase of the impact ↑

Source: Millennium Ecosystem Assessment

Table 20.1. *Drivers of change in ecosystem services. Source: Millennium Ecosystem Assessment (MA, 2005).*

participation in primary school education (*human capital*), other measures of human capital (e.g., health measures), *access to affordable investment goods* and the *initial level of per capita income* (access to resources).

20.3.3 Two-way causality between sustainable development and adaptive capacity

It has become increasingly evident, especially since the TAR (IPCC, 2001b), that the pace and character of development influences adaptive capacity and that adaptive capacity influences the pace and character of development. It follows that development paths, and the choices that define them, will affect the severity of climate impacts, not only through changes in exposure and sensitivity, but also through changes in the capacities of systems to adapt. This includes local-scale disaster risk reduction and resource management (e.g., Shaw, 2006; Jung et al., 2005), and broader social dimensions including governance, societal engagement and rights, and levels of education (Haddad, 2005; Tompkins and Adger, 2005; Brooks et al., 2005; Chapter 17, Section 17.3).

Munasinghe and Swart (2005) and Swart et al. (2003) argued that sustainable development measures and climate-change policies, including adaptation, can reinforce each other; Figure 20.2 portrays some of the texture of the interaction that they envisioned. Although scholarly papers on adaptation began to appear in the 1980s, it was not until the 2001 Marrakech Accords that a policy focus on adaptation within the United Nations

Framework Convention on Climate Change (UNFCCC) developed (Schipper, 2006). Klein et al. (2005) suggest that adaptation has not been seen as a viable option, in part because many observers see market forces creating the necessary conditions for adaptation even in the absence of explicit policies and, in part, because understanding of how future adaptation could differ from historical experience is limited.

Efforts to promote alternative development pathways that are more sustainable could include measures to reduce non-renewable energy consumption, for example, or shifting construction of residential or industrial infrastructure to avoid high-risk areas (AfDB et al., 2004). The MA (2005) attempted to describe a global portrait of such a pathway in its "Techno Garden" scenario. In this future, an inter-connected world promotes expanded use of innovative technology, but its authors warned that technology may not solve all problems and could lead to the loss of indigenous cultures. Climate-change measures could also encounter such limitations. Gupta and Tol (2003) describe various climate-policy dilemmas including competition between human rights and property rights.

Adaptation measures embedded within climate-change policies could, by design, try to reduce vulnerabilities and risks by enhancing the adaptive capacity of communities and economies. This would be consistent with sustainability goals. Researchers and practitioners should not equate vulnerability to poverty, though, and they should not consider adaptation and adaptive capacity in isolation. Brooks et al. (2005) conclude that efforts to promote adaptive capacity should incorporate aspects of education, health and governance and thereby extend the context beyond a particular stress (such as climate change) to include factors that are critical in a broader development context. Haddad (2005) noted the critical role played here by general rankings of economic development performance and general reflections of national and local goals and aspirations, and explained how different people might choose different development from the same set of alternatives even if they had the same information.

Past adaptation and development experience displays mixed results. Kates (2000) described several historic climate adaptations (e.g., drought in the Sahel) and development measures (e.g., the Green Revolution) and argued that development measures that were generally consistent with climate adaptation often benefited some groups (e.g., people with access to resources) while harming others (e.g., poor populations, indigenous peoples). Ford et al. (2006) showed that unequal acquisition of new technologies can, under some circumstances, increase vulnerability to external stresses by weakening social networks and thereby altering adaptive capacity within communities and between generations. Belliveau et al. (2006) makes the link to climate explicit by observing that adaptation to non-climatic forces, without explicitly considering climate, can lead to increased vulnerability to climate because adapting previous adaptations can be expensive.

Future links between sustainable development and climate change will evolve from current development frameworks; but recognising the exposure of places and peoples to multiple stresses (Chapter 17; Chapter 19; Section 20.3.1) and accepting the challenge of mainstreaming adaptation into development planning will be critical in understanding what policies will work where and when. For example, in the Sudan, there is a risk that development efforts focusing on short-term relief can undermine community coping capacity (Elasha, 2005). In the mitigation realm, incentives for carbon sequestration could promote hybrid forest plantations and therefore pose a threat to biodiversity and ecosystem adaptability (Caparrós and Jacquemont, 2003; Chapter 18). Development decisions can also produce cumulative threats. In the Columbia River Basin, for

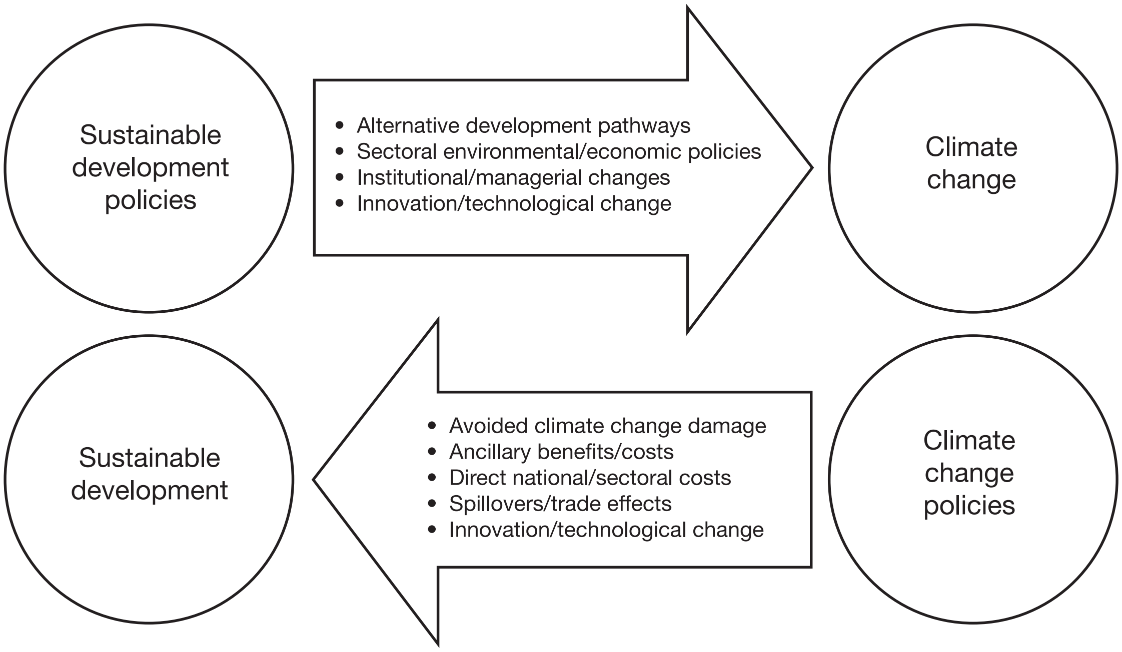


Figure 20.2. *Two-way linkages between climate and sustainable development. Source: Swart et al. (2003).*

instance, extensive water resource development can influence basin management with multiple objectives within scenarios of climate change because climate impacts on stream-flow cause policy dilemmas when decision-makers must balance hydroelectricity production and fisheries protection (Hamlet, 2003; Payne et al., 2004). Restoring in-stream flow to present-day acceptable (but sub-optimum) levels could, in particular, cause hydroelectricity production to decline and production from fossil fuel sources to rise. Interactions of this sort raise important questions on the analysis of the causes of recent climate-related disasters. For example, are observed trends in injuries/fatalities and property losses (Mileti, 1999; Mirza, 2003; MA, 2005; Munich Re, 2005) due to unsustainable development policies, climate change or a mixture of different factors? Could policy interventions reduce these losses in ways that would still meet broader objectives of sustainable development? Some proposed responses for Africa are described in Low (2005) and AfDB et al. (2004).

Globalisation also adds complexity to the management of common-pool resources because increased interdependence makes it more difficult to find equitable solutions to development problems (Ostrom et al., 1999). Increases in the costs associated with various hazards and the prospects of cumulative environmental/economic threats have been described as syndromes. Schellnhuber et al. (1997) identified three significant categories: over-utilisation (e.g., over-cultivation of marginal land in the Sahel), inconsistent development (e.g., urban sprawl and associated destruction of landscapes) and hazardous sinks (e.g., large-scale diffusion of long-lived substances). Schellnhuber et al. (2002) and Lüdeke et al. (2004) describe possible future distributions of some of these syndromes. They suggest how mechanisms of mutual reinforcement, including climate change and development drivers, can help to identify regions where syndromes may expand and others where they might contract.

20.4 Implications for environmental quality

The inseparability of environment and development has been widely recognised ever since the Brundtland Commission (WCED, 1987). In the United Nations' Millennium Development Goals (MDGs), for example, environmental considerations are reflected in the 7th goal and the operative target, among others, is to reverse loss of environmental resources by 2015. Overall, how to meet the target of integrating the principles of sustainable development in national policy and reversing the loss of environmental resources remains a partially answered question for most countries (Kates et al., 2005).

Interest in environmental indicators and performance indices to monitor change has increased recently. A compilation of different sustainable development indicators by Kates et al. (2005) showed that most implicitly or explicitly build from reflections of the health of environmental and ecological resources and/or the quality of environmental and ecological services. This is relevant in both developed and developing countries, but the drivers encouraging sustainable management are arguably strongest in the developed world. Huq and Reid (2004) and Agrawala (2004) have noted, though, that climate change is being increasingly recognised as a key factor that could affect the (sustainable) development of developed and developing countries alike. The Philippine Country Report (1999) identified 153 sustainable development indicators; some pertain to climate-change variables such as level of greenhouse gas emissions, but none refer explicitly to adaptation. There is, for example, no mention within the MDGs of potential changes in climate-related disasters or of the need to include climate-change adaptation within development programmes (Reid and Alam, 2005). This is not unusual, because links between sustainable development and climate change have historically been defined primarily in terms of mitigation.

Promoting environmental quality is about more than encouraging sustainable development or adaptive capacity. It is also about transforming use practices for environmental resources into sustainable management practices. In many countries and sectors, stakeholders who manage natural resources (such as individual farmers, small businesses or major international corporations) are susceptible, over time, to variations in resource availability and hazards; they are currently seeking to revise management practices to make their actions more sustainable. Hilson (2001), for example, describes efforts in the mineral extraction industry where the relevant players include public agencies operating at many scales (from local to national to international). Definitions of sustainability vary across sectors, but their common theme is to change the way resources are exploited or hazards are managed so that adverse impacts downstream or for subsequent generations are reduced. Climate change is, however, seldom listed among the stressors that might influence sustainability. Arnell and Delaney (2006) note, though, that water management in the United Kingdom is an exception.

Published literature on the links between sustainable management of natural resources and the impacts of and adaptation to climate change is extremely sparse. Most focuses on engineering and management techniques which achieve management objectives, such as a degree of protection against flood hazard or a volume of crop production, while having smaller impacts on the environment. Turner (2004) and Harman et al. (2002) speak to this point, but very few engineering analyses consider explicitly how the performance of these measures is affected by climate change or how suitable they would be in the face of a changing climate. Kundzewicz (2002) demonstrated how non-structural flood management measures can be sustainable adaptations to climate change because they are relatively robust to uncertainty. On the other hand, as shown in Clark (2002) and Kashyap (2004), much of the literature on integrated water management in the broadest sense emphasises adaptation to climatic variability and change through the adoption of sustainable and integrated approaches.

Several studies have highlighted the benefits of adopting more sustainable practices, in terms of reduced costs, increased efficiency or financial performance more broadly interpreted. Johnson and Walck (2004) offer an example from forestry while Epstein and Roy (2003) are illustrative of a more expansive context. None of these studies explicitly consider the effects of climate change on the benefits of adopting more sustainable practices; and none of the literature on mechanisms for incorporating sustainable behaviour into organisational practice and monitoring its implementation (e.g., Jasch, 2003; Figge and Hahn, 2004) consider how to incorporate the effects of climate change into mechanisms or monitoring procedures.

Clark (2002) and Bansal (2005) identified several drivers behind moves to become more sustainable. First, altered legal or regulatory requirements may have an effect. Many governments have adopted legislation aimed at encouraging the sustainable use of the natural environment, and some explicitly include reference to climate change. For example, Canada and some EU member states have begun to incorporate climate change in their environmental policies, particularly in the structures of required environmental impact assessments. The hope is that the impact of present and future climates on development projects might thereby be reduced (EEA, 2006; Barrow and Lee, 2000). Ramus (2002) and Thomas et al. (2004) have observed that internally-generated efforts to improve procedures (e.g., following an ethical position held by an influential champion, responding to the desire to reduce costs or risks, or attempting to attract potential clients) can push systems toward sustainability.

Of course, stakeholder expectations may change over time. While these dynamic drivers may encourage sustainable management, they may not in themselves be directly related to concerns over the impacts of and adaptation to climate change. Kates et al. (2005) noted that the principles, goals and practices of sustainability are not fixed and immutable; they are ‘works in progress’ because the tension between economic development and environmental protection has been opened to reinterpretation from different social and ecological perspectives.

20.5 Implications for risk, hazard and disaster management

The International Decade for Natural Disaster Reduction (1990 to 1999) led to a fundamental shift in the way disasters are viewed: away from the notion that disasters were temporary disruptions to be managed by humanitarian responses and technical interventions and towards a recognition that disasters are a function of both natural and human drivers (ISDR, 2004; UNDP, 2004). The concept of *disaster risk management* has evolved; it is defined as the systematic management of administrative decisions, organisations, operational skills and abilities to implement policies, strategies and coping capacities of society or individuals to lessen the impacts of natural and related environmental and technological hazards (ISDR, 2004). This includes measures to provide not only emergency relief and recovery, but also *disaster risk reduction* (ISDR, 2004); i.e., the development and application of policies, strategies and practices designed to minimise vulnerabilities and the impacts of disasters through a combination of technical measures to reduce physical hazards and to enhance social and economic capacity to adapt. Disaster risk reduction is conceived as taking place within the broad context of sustainable development (ISDR, 2004).

In practice, however, there has been a disconnect between disaster risk reduction and sustainable development, due to a combination of institutional structures, lack of awareness of the linkages between the two, and perceptions of ‘competition’ between hazard-based risk reduction, development needs and emergency relief (Yamin, 2004; Thomalla et al., 2006). The disconnect persists despite an increasing recognition that natural disasters seriously challenge the ability of countries to meet targets associated with the Millennium Development Goals (Schipper and Pelling, 2006).

A disconnect also exists between disaster risk reduction and adaptation to climate change, again reflecting different institutional structures and lack of awareness of linkages (Schipper and Pelling, 2006; O’Brien et al., 2006). Disaster risk reduction, for example, is often the responsibility of civil defence agencies, while climate-change adaptation is often covered by environmental or energy departments (Thomalla et al., 2006). Disaster risk reduction tends to focus on sudden and short-lived disasters, such as floods, storms, earthquakes and volcanic eruptions, and has tended to place less emphasis on ‘creeping onset’ disasters such as droughts. Many disasters covered by disaster risk reduction are not affected by climate change. However, there is an increasing recognition of the linkages between disaster risk reduction and adaptation to climate change, since climate change alters not only the physical hazard but also vulnerability. Sperling and Szekely (2005) note that many of the impacts associated with climate change exacerbate or alter existing threats, and adaptation measures can benefit from practical experience in disaster risk reduction. However, some effects of climate change are new within human history (such as the effects of sea-level rise), and there is little experience to tackle such impacts. Sperling and Szekely (2005) therefore state that co-ordinated action to address both existing and new challenges becomes urgent. There is great opportunity for collaboration in the assessment of current and future vulnerabilities, in the use of assessment tools (Thomalla et al., 2006) and through capacity-building measures. Incorporating climate change and its uncertainty into measures to reduce vulnerability to hazard is essential in order for them to be truly sustainable (O’Hare, 2002), and climate change increases the urgency to integrate disaster risk management into development interventions (DFID, 2004).

There are, effectively, two broad approaches to disaster risk reduction, and adaptation to climate change can be incorporated differently into each. The top-down approach is based on institutional responses, allocation of funding and agreed procedures and practices (O’Brien et al., 2006). It is the approach followed in most developed countries, and adaptation to climate change can be implemented by changing guidelines and procedures. In the United Kingdom, for example, design flood magnitudes can be increased by 20% to reflect possible effects of climate change (Richardson, 2002). However, institutional inertia and strongly embedded practices can make it very difficult to change. Olsen (2006), for example, shows how major methodological and institutional changes are needed before flood management in the USA can take climate change (and its uncertainty) into account. The bottom-up approach to disaster risk reduction is based on enhancing the capacity of local communities to adapt to and prepare for disaster (see, for example, Allen, 2006; Blanco, 2006). Actions here include dissemination of technical knowledge and training, awareness raising, accessing local knowledge and resources, and mobilising local communities (Allen, 2006). Climate change can be incorporated in this approach through awareness raising and the transmission of technical knowledge to local communities, but bridging the gap between scientific knowledge and local application is a key challenge (Blanco, 2006).

Reducing vulnerability to current climatic variability can effectively reduce vulnerability to increased hazard risk associated with climate change (e.g., Kashyap, 2004; Goklany, 2007; Burton et al., 2002; Davidson et al., 2003; Robledo et al., 2004). To a large extent, adaptation measures for climate variability and extremes already exist. Measures to reduce current vulnerability by capacity building rather than distribution of disaster relief, for example, will increase resilience to changes in hazard caused by climate change (Mirza, 2003). Similarly, the implementation of improved warning and forecasting methods and the adoption of some land-use planning measures would reduce both current and future vulnerability. However, many responses to current climatic variability would not in and of themselves be a sufficient response to climate change. For example, a changing climate could alter the design standard of a physical defence, such as a realigned channel or a defence wall. It could alter the effectiveness of building codes based on designing against specified return period events (such as the 10-year return period gust). It could alter the area exposed to a potential hazard, meaning that development previously assumed to be ‘safe’ was now located in a risk area. Finally, it could introduce hazards previously not experienced in an area. Burton and van Aalst (2004), in their assessment of the World Bank Country Strategic Programmes and project cycle, identify the need to assess the success of current adaptation to present-day climate risks and climate variability, especially as they may change with climate change.

20.6 Global and aggregate impacts

Three types of aggregate impacts are commonly reported. In the first, impacts are computed as a percent of gross domestic product (GDP) for a specified rise in global mean temperature. In the second, impacts are aggregated over time and discounted back to the present day along specified emissions scenarios such as those documented in Nakićenović and Swart (2000) under specified assumptions about economic development, changes in technology and adaptive capacity. Some of these estimates are made at the global level, but others aggregate a series of local or regional impacts to obtain a global total. A third type of estimate has recently attracted the most attention. Called the social cost of carbon (SCC), it is an estimate of the economic value of the extra (or marginal) impact caused by the emission of one more tonne of carbon (in the form of carbon dioxide) at any point in time; it can, as well, be interpreted as the marginal benefit of reducing carbon emissions by one tonne. Researchers calculate SCC by summing the extra impacts for as long as the extra tonne remains in the atmosphere – a process which requires a model of atmospheric residence time and a means of discounting economic values back to the year of emission.

This section provides a brief discussion of the historical and current status of efforts to produce aggregate estimates of the impacts of climate change. The first sub-section focuses attention on economic estimates and the second begins to expand the discussion by reporting estimates calibrated in alternative metrics. It is in this expansion that the implications of spatial and temporal diversity in systems’ exposures and sensitivities to climate change begin to emerge.

20.6.1 History and present state of aggregate impact estimates

Most of the aggregate impacts reported in IPCC (1996) were of the first type; they monetised the likely damage that would be caused by a doubling of CO_2 concentrations. For developed countries, estimated damages were of the order of 1% of GDP. Developing countries were expected to suffer larger percentage damages, so mean global losses of 1.5 to 3.5% of world GDP were therefore reported. IPCC (2001a) reported essentially the same range because more modest estimates of market damages were balanced by other factors such as higher non-market impacts and improved coverage of a wide range of uncertainties. Most recently, Stern (2007) took account of a full range of both impacts and possible outcomes (i.e., it employed the basic economics of risk premiums) to suggest that the economic effects of unmitigated climate change could reduce welfare by an amount equivalent to a persistent average reduction in global per capita consumption of at least 5%. Including direct impacts on the environment and human health (i.e., ‘non-market’ impacts) increased their estimate of the total (average) cost of climate change to 11% GDP; including evidence which indicates that the climate system may be more responsive to greenhouse-gas emissions than previously thought increased their estimates to 14% GDP. Using equity weights to reflect the expectation that a disproportionate share of the climate-change burden will fall on poor regions of the world increased their estimated reduction in equivalent consumption per head to 20%.

Figure 20.3 compares the Stern (2007) relationship between global impacts and increases in global mean temperature with estimates drawn from earlier studies that were assessed in IPCC (2001b). The Stern (2007) trajectories all show negative impacts for all temperatures; they reflect the simple assumptions of the underlying PAGE2002 model and a focus on risks associated with higher temperatures. The Mendelsohn et al. (1998) estimates aggregate regional monetary damages (both positive and negative) without equity weighting. The two Nordhaus and Boyer (2000) trajectories track aggregated regional monetary estimates of damages with and without population-based equity weighting; they do include a ‘willingness to pay (to avoid)’ reflection of the costs of abrupt change. The two Tol (2002) trajectories track aggregated regional monetary estimates of damages with and without utility-based equity weighting. The various relationships depicted in Figure 20.3 therefore differ in their treatment of equity weighting, in their efforts to capture the potential of beneficial climate change (in, for example,

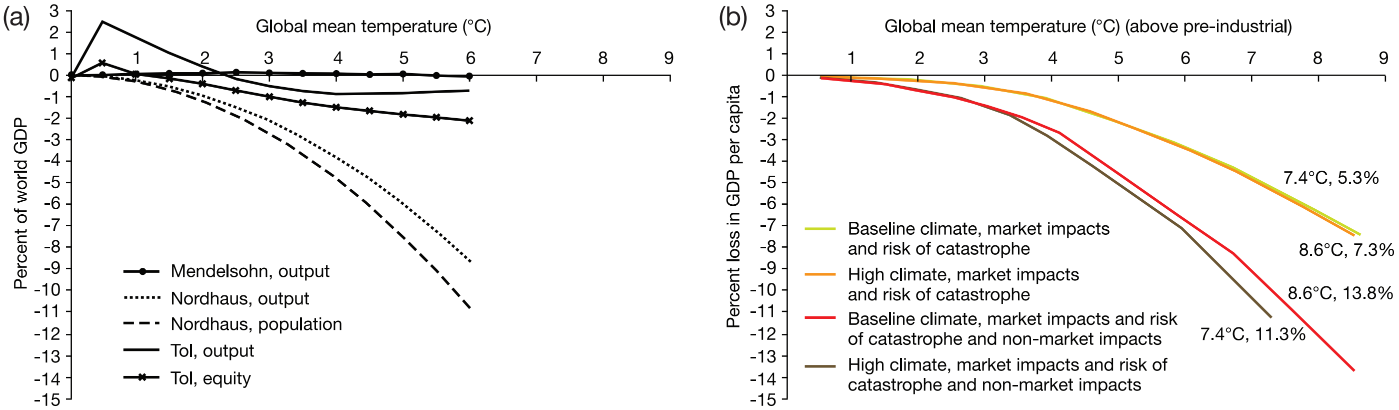


Figure 20.3. *(a) Damage estimates, as a percent of global GDP, as correlated with increases in global mean temperature. Source: IPCC (2001b). (b) Damage estimates, as a percent of global GDP, are correlated with increases in global mean temperature. Source: Stern (2007).*

agriculture for small increases in temperature; see Chapter 5, Section 5.4.7) and in their treatment of the risks of catastrophe for large increases in temperature.

Early calculations of the SCC (IPCC (1996) estimates ranged from US$5 to $125 per tonne of carbon in 1990 dollars) stimulated recurring interest, as part of wider post-Kyoto considerations, in the economic benefits of climate-change policy (Watkiss et al., 2005). After surveying the literature, Clarkson and Deyes (2002) proposed a central value of US$105 per tonne of carbon (in year 2000 prices) for the SCC, with upper and lower values of US$50 and $210 per tonne. Pearce (2003) argued that 3% is a reasonable representation of a social discount rate so the probable range of the SCC in 2003 should have been in the region of US$4 to 9 per tonne of carbon. Tol (2005) gathered over 100 estimates of the SCC from 28 published studies and combined them to form a probability density function; it displayed a median of US$14 per tonne of carbon, a mean of US$93 per tonne and a 95th percentile estimate equal to US$350 per tonne. Peer-reviewed studies generally reported lower estimates and smaller uncertainties than those which were not; their mean was US$43 per tonne of carbon with a standard deviation of US$83. The survey showed that 10% of the estimates were negative; to support these estimates, the climate sensitivity was assumed to be low and small increases in global mean temperature brought benefits (as suggested by the Tol (2002) trajectories in Figure 20.3).

Notwithstanding the differences in damage sensitivity to temperature reflected in Figure 20.3, the effect of the discount rate (see glossary) on estimates of SCC is most striking. The 90th percentile SCC, for instance, is US$62/tC for a 3% pure rate of time preference, $165/tC for 1% and $1,610/tC for 0%. Stern (2007) calculated, on the basis of damage calculations described above, a mean estimate of the SCC in 2006 of US$85 per tonne of CO_2 (US$310 per tonne of carbon). Had it been included in the Tol (2005) survey, it would have fallen well above the 95th percentile, in large measure because of their adoption of a low 0.1% pure rate of time preference. Other estimates of the SCC run from less than US$1 per tonne to over US$1,500 per tonne of carbon. Downing et al. (2005) argued that this range reflects uncertainties in climate and impacts, coverage of sectors and extremes, and choices of decision variables. Tol (2005) concluded, using standard assumptions about discounting and aggregation, that the SCC is unlikely to exceed US$50/tC. In contrast, Downing et al. (2005) concluded that a lower benchmark of US$50/tC is reasonable for a global decision context committed to reducing the threat of dangerous climate change and including a modest level of aversion to extreme risks, relatively low discount rates and equity weighting.

Climate change is not caused by carbon dioxide alone, and integrated assessment models can calculate the social cost of each greenhouse gas under consistent assumptions. For instance, the mean estimate from the PAGE2002 model for the social cost of methane is US$105 per tonne emitted in 2001, in year 2000 dollars, with a 5 to 95% uncertainty range of US$25 to $250 per tonne. The estimate for the social cost of SF_6 is US$200,000 per tonne emitted in 2001 with a 5 to 95% range of US$45,000 to $450,000 per tonne. These are all higher than the corresponding US$19 per tonne estimate for SCC that is surrounded by a 5 to 95% range of US$4 to $50 per tonne (Hope, 2006b). It has been known since IPCC (1996) that the SCC will increase over time; current knowledge suggests a 2.4% per year rate of growth. The social cost of methane will grow 50% faster because of its shorter atmospheric lifetime. Unlike later emissions, any extra methane emitted today will have disappeared before the most severe climate-change impacts occur (Watkiss et al., 2005).

Tol (2005) finds that much of the uncertainty in the estimates of the SCC can be traced to two assumptions: one on the discount rate and the other on the equity weights that are used to aggregate monetised impacts over countries. In most other policy areas, the rich do not reveal as much concern for the poor as is implied by the equity weights used in many models. Downing et al. (2005) state that the extreme tails of the estimates of the SCC depend as much on decision values (such as discounting and equity weighting) as on the climate forcing and uncertainty in the underlying impact models. Integrated models are always simplified representations of reality. To be comprehensive, other social and cultural values need to be given comparable weights to economic values, and there are prototype integrated assessment models to demonstrate this (Rotmans and de Vries, 1997).

Table 20.2 shows the six major influences calculated by PAGE2002 and reported in Hope (2005). That the list can be divided into two scientific and four socio-economic parameters is another strong argument for the building of integrated assessment models (IAMs); models that are exclusively scientific, or exclusively economic, would omit parts of the climate-change problem which still contain profound uncertainties. The two top influences are the climate sensitivity and the pure rate of time preference. Climate sensitivity is positively correlated with the SCC, but the pure time preference rate is negatively correlated with the SCC. Non-economic impact ranks third and economic impact ranks sixth (Hope, 2005).

A few models have existed for long enough to trace the changes in their estimates of the SCC over time. Table 20.3 shows how the results from three integrated assessment models have evolved over the last 15 years. The DICE and PAGE estimates have not changed greatly over the years, but this gives a misleading impression of stability. The values from PAGE have changed little because several quite significant changes have approximately cancelled each other out. In the later studies, lower estimates for market-sector impacts in developed countries are offset by higher non-market impacts, equity weights and inclusion of estimates of the possible impacts of large-scale discontinuities (Tol, 2005).

Hitz and Smith (2004) found that the relationships between global mean temperature and impacts of the sort displayed in Figure 20.3 are not consistent across sectors for modest amounts of warming. Beyond an approximate 3 to 4°C increase in global mean temperature above pre-industrial levels, all sectors (except possibly forestry) show increasingly adverse impacts. Tol (2005) found that few studies cover non-market damages, the risk of potential extreme weather, socially contingent effects, or the potential for longer-term catastrophic events. Therefore, uncertainty in the value of the SCC is derived not only from the 'true' value of impacts that are covered by the models, but also from impacts that have not yet been quantified and valued. As argued in Watkiss et al. (2005) and displayed in Figure 20.4, existing estimates of SCC are products of work that spans only a sub-set of impacts for which complete estimates might be calculated. Nonetheless, current estimates do provide enough information to support meaningful discussions about reducing the emissions of CO_2, methane and other greenhouse gases, and the appropriate trade-off between gases.

Nonetheless, estimates of SCC offer a consistent way to internalise current knowledge about the impacts of climate change into development, mitigation and/or adaptation decisions that the private and public sector will be making over the near term (Morimoto and Hope, 2004). According to economic theory, if the social cost calculations were complete and markets were perfect, then efforts to cut back the emissions of greenhouse gases would continue as long as the marginal cost of the cutbacks were lower than the social cost of the impacts they cause. If taxes were used, then they should be set equal to the SCC. If tradable permits were used, then their price should be the same as the SCC. If their price turns out to be lower than the social cost, then the total allocation of permits would have been too large and *vice versa*. In any comparison between greenhouse gases, according to Pearce (2003), the SCC is the correct figure to use. For reference, spot prices for permits in the European Carbon Trading Scheme since its inception early in 2005 started out towards the bottom end of the range of the SCC, but they rose quickly to around US$100 per tonne of carbon before falling by about 50% in the early summer of 2006 amid concerns that the carbon allowances allocated by the European Commission at the start of the scheme had been too generous. In the real world, markets are not perfect, calculations of the SCC are far from complete, and both mask significant differences between regions and types of impacts.

Table 20.2. *Major factors causing uncertainty in the social cost of carbon. Relative importance is measured by the magnitude of the partial rank correlation coefficient between the parameter and the SCC, with the most important indexed to 100. A + sign shows that an increase in this parameter leads to an increase in the SCC and vice versa. Source: Hope (2005).*

Parameter	Definition	Sign	Range	Importance
Climate sensitivity	Equilibrium temperature rise for a doubling of CO_2 concentration	+	1.5 to 5°C	100
PTP rate	Pure time preference for consumption now rather than in 1 year's time	-	1 to 3% /yr	66
Non-economic impact	Valuation of non-economic impact for a 2.5°C temperature rise	+	0 to 1.5% of GDP	57
Equity weight	Negative of the elasticity of marginal utility with respect to income	-	0.5 to 1.5	50
Climate change half life	Half life in years of global response to an increase in radiative forcing	-	25 to 75 years	35
Economic impact	Valuation of economic impact for a 2.5°C temperature rise	+	-0.1 to 1.0% of GDP	32

Note: non-economic and economic impact ranges apply to Europe; impacts in other regions are expressed as a multiple of this.

Table 20.3. *Estimates of the social cost of carbon over time from three models (in constant 2000 US$). Sources: DICE best guesses of Nordhaus and Boyer (2000) are from Pearce (2003); FUND estimates are from Tol (1999), and 25 to 75% range with green book discounting and equity weights from Downing et al. (2005); PAGE 5th and 95th percentile ranges from Plambeck and Hope (1996), rebased to year 2000, and Hope (2006a).*

Date of estimate	1990	1995	2000	2005
DICE	$10	$7	$6	
FUND			$9 to $23	-$15 to $110
PAGE		$12 to $60		$4 to $51

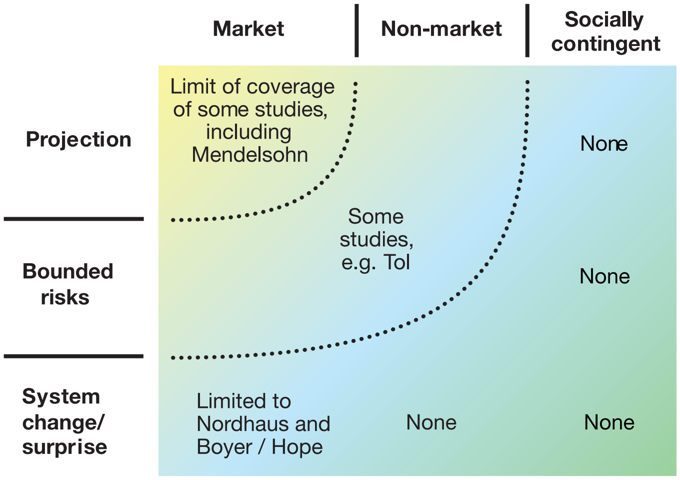


Figure 20.4. *Coverage of studies that compute estimates of the social cost of carbon against sources of climate-related risk. Coverage of most studies is limited to market-based sectors, and few of them move beyond the upper left corner to include bounded risks and abrupt system change. Source: Watkiss et al., 2005.*

20.6.2 Spatially-explicit methods: global impacts of climate change

Warren (2006) and Hitz and Smith (2004) observe that most impact assessments are conducted at the local scale. It is therefore extremely difficult to estimate impacts across the global domain from these localised studies. A small number of studies have used geographically-distributed impacts models to estimate the impacts of climate change across the global domain. The "Fast Track" studies (Arnell, 2004; Nicholls, 2004; Arnell et al., 2002; Levy et al., 2004; Parry et al., 2004; Van Lieshout et al., 2004) used a consistent set of scenarios and assumptions to estimate the effects of scenarios based on the HadCM3 climate model on water resource availability, food security, coastal flood risk, ecosystem change and exposure to malaria. Schroeter et al. (2005) used a similar approach in the ATEAM project to tabulate impacts across Europe using scenarios constructed from a larger number of climate models. Both these sets of studies used a wide range of metrics that varied across sectors. Table 20.4 summarises some of the global-scale impacts of defined climate-change scenarios. Although the precise numbers depend on the climate model used and some key assumptions (particularly the effect of increased CO_2 concentrations on crop productivity), it is clear that the future impacts of climate change are dependent not only on the rate of climate change, but also on the future social, economic and technological state of the world. Impacts are greatest under an A2 world, for example, not because the climate change is greatest but because there are more people to be impacted. Impacts also vary regionally and Table 20.5 summarises impacts by major world region. The assumed effect of CO_2 enrichment on crop productivity has a major effect on estimated changes in population at risk of hunger (Chapter 5, Section 5.4.7).

Table 20.6 compares the global impacts of a 1% annual increase in CO_2 concentrations (i.e., the IS92a scenario, see IPCC, 1992) with the impacts of emissions trajectories stabilising at 750 (S750) and 550 (S550) ppm (Arnell et al., 2002). The results are not directly comparable to those reported in Table 20.4, because different population assumptions, methodologies and indicators were employed in their preparation. Nevertheless, the results suggest that aiming for stabilisation at 750 ppm has a relatively small effect on impacts in most sectors in comparison with 550 ppm stabilisation. The S550 pathway has a greater apparent impact on exposure to hunger because higher CO_2 concentrations under S750 result in a greater increase in crop productivity (but again, note that CO_2-enrichment effects are highly uncertain).

Each of these tables present *indicators* of impact which ignore adaptations that will occur over time. They can therefore be seen as indicative of the challenge to be overcome by adaptations to offset some of the impacts of climate change. Incorporating adaptation into global-scale assessments of the impacts of climate change is currently difficult for a number of reasons (including diversity of circumstances, diversity of potential objectives of adaptation, diversity of ways of meeting adaptation objectives and uncertainty over the effectiveness of adaptation options) and remains an area where more research is needed.

Table 20.4. *Global-scale impacts of climate change by 2080.*

	Climate and socio-economic scenario			
	A1FI	A2	B1	B2
Global temperature change (°C difference from the 1961-1990 period)	3.97	3.21 to 3.32	2.06	2.34 to 2.4
Millions of people at increased risk of hunger (Parry et al., 2004); no CO_2 effect	263	551	34	151
Millions of people at increased risk of hunger (Parry et al., 2004); with maximum direct CO_2 effect	28	-28 to -8	12	-12 to +5
Millions of people exposed to increased water resources stress (Arnell, 2004)	1256	2583 to 3210	1135	1196 to 1535
Additional numbers of people (millions) flooded in coastal floods each year, with lagged evolving protection (Nicholls, 2004)	7	29	2	16

Note: change in climate derived from the HadCM3 climate model. Impacts are compared to the situation in 2080 with no climate change. The range of impacts under the SRES A2 and B2 scenarios (Nakićenović and Swart, 2000) represents the range between different climate simulations. The figures for additional millions of people flooded in coastal floods assumes a low rate of subsidence and a low rate of population concentration in the coastal zone.

Table 20.5. *Regional-scale impacts of climate change by 2080 (millions of people).*

	Population living in watersheds with an increase in water-resources stress (Arnell, 2004)				Increase in average annual number of coastal flood victims (Nicholls, 2004)				Additional population at risk of hunger (Parry et al., 2004)[1] Figures in brackets assume maximum direct CO_2-enrichment effect			
	Climate and socio-economic scenario:											
	A1	A2	B1	B2	A1	A2	B1	B2	A1	A2	B1	B2
Europe	270	382-493	233	172-183	1.6	0.3	0.2	0.3	0	0	0	0
Asia	289	812-1197	302	327-608	1.3	14.7	0.5	1.4	78 (6)	266 (-21)	7 (2)	47 (-3)
North America	127	110-145	107	9-63	0.1	0.1	0	0	0	0	0	0
South America	163	430-469	97	130-186	0.6	0.4	0	0.1	27 (1)	85 (-4)	5 (2)	15 (-1)
Africa	408	691-909	397	492-559	2.8	12.8	0.6	13.6	157 (21)	200 (-2)	23 (8)	89 (-8)
Australasia	0	0	0	0	0	0	0	0	0	0	0	0

Note: change in climate derived from the HadCM3 climate model. Impacts are compared to the situation in 2080 with no climate change. The range of impacts under the SRES A2 and B2 scenarios (Nakićenović and Swart, 2000) represents the range between different climate simulations. The figures for additional millions of people flooded in coastal floods assumes a low rate of subsidence and a low rate of population concentration in the coastal zone.

[1] Analysis of project results carried out for this table.

Table 20.6. *Global-scale impacts under unmitigated and stabilisation pathways. Source: Arnell et al., 2002.*

	2050			2050		
	Unmitigated	Scenario: S750	S550	Unmitigated	Scenario: S750	S550
Approximate equivalent CO_2 concentration (ppm)	520	485	458	630	565	493
Approximate global temperature change (°C difference from 1961 to 1990)	2.0	1.3	1.1	2.9	1.7	1.2
Area potentially experiencing vegetation dieback (million km^2)	1.5 to 2.7	2	0.7	6.2 to 8	3.5	1.3
Millions of people exposed to increased water stress	200 to 3200	2100	1700	2830 to 3440	2920	760
Additional people flooded in coastal floods (millions/year)	20	13	10	79 to 81	21	5
Population at increased risk of hunger (millions)	-3 to 9	7	5	69 to 91	16	43

Note: climate scenarios based on HadCM2 simulations: the range with unmitigated emissions reflects variation between ensemble simulations.

Aggregation of impacts to regional and global scales is another key problem with such geographically-distributed impact assessments. Tables 20.4 to 20.6, for example, keep track of people living in watersheds who will face increased water-related stress. Of course, many people live in watersheds where climate change increases runoff and therefore may apparently see *reduced* water-related stress (if they see increased risk of flooding). Simply calculating the 'net' impact of climate change, however, is complicated, particularly where 'winners' and 'losers' live in different geographic regions, or where 'costs' and 'benefits' are not symmetrical. Watersheds with an increase in runoff, for example, are concentrated in east Asia, while watersheds with reduced runoff are much more widely distributed. Similarly, the adverse effects felt by 100 million people exposed to increased water stress could easily outweigh the 'benefits' of 100 million people with reduced stress.

The Defra Fast Track and ATEAM studies both describe impacts along defined scenarios, so it is difficult to infer the effects of different rates or degrees of climate change on different socio-economic worlds. A more generalised approach applies a wide range of climate scenarios representing different rates of change to estimate impacts for specific socio-economic contexts. Leemans and Eickhout (2004), for example, show that most species, ecosystems and landscapes would be impacted by increases of global temperature between 1 and 2°C above 2000 levels. Arnell (2006) showed that an increase in temperature of 2°C above the 1961 to 1990 mean by 2050 would result in between 550 and 900 million people suffering an increase in water-related stress in both the SRES (Special Report on Emissions Scenarios, Nakićenović and Swart, 2000) A1 and B1 worlds. In this case, the range between estimates represents the effect of different changes in rainfall patterns for a 2°C warming.

20.7 Implications for regional, sub-regional, local and sectoral development; access to resources and technology; equity

The first sub-section here addresses issues of equity and access to resources as measured by the likelihood of meeting Millennium Development Targets by 2015 and Millennium Development Goals until the middle of this century. Vulnerability to climate change is unlikely to be the dominant cause of trouble for most nations as they try to reach the 2015 Targets. However, an assortment of climate-related vulnerabilities will seriously impede progress in achieving the mid-century goals. The second sub-section considers the range of these vulnerabilities across regions and sectors in 2050 and 2100 before the last offers portraits of the global distribution of vulnerability with and without enhanced adaptive capacity and/or mitigation efforts.

20.7.1 Millennium Development Goals – a 2015 time slice

The Millennium Development Goals (MDGs) are the product of international consensus on a framework by which nations can assess tangible progress towards sustainable development; they are enumerated in Table 20.7. UN (2005) provides the most current documentation of the 8 MDGs, the 11 specific targets for progress by 2015 or 2020 and the 32 quantitative indicators that are being used as metrics. This chapter has made the point that sustainable development and adaptive capacity for coping with climate change have common determinants. It is easy, therefore, to conclude that climate change has the potential to affect the progress of nations and societies towards sustainability. MA (2005) supports this conclusion. Climate-change impacts on the timing, flow and amount of available freshwater resources could, for example, affect the ability of developing countries to increase access to potable water: Goal #7, Target #10, Indicator #30 (UN, 2005). It is conceivable that climate change could have measurable consequences, in some parts of the world at least, on the indicators of progress on food security: Goal #1, Target #2, Indicators #4 and #5 (UN, 2005). Climate-change impacts could possibly affect one indicator in Goal #6 (prevalence and death rates associated with malaria), over the medium term (UN, 2005). The list can be extended.

The anthropogenic drivers of climate change, *per se*, affect MDG indicators directly in only two ways: in terms of energy use per dollar GDP and CO_2 emissions per capita. While climate change may, with high confidence, have the potential for substantial effects on aspects of sustainability that are important for the MDGs, the literature is less conclusive on whether the metrics themselves will be sensitive to either the effects of climate change or to progress concerning its drivers, especially in the near term. The short-term targets of the MDGs (i.e., the 2015 to 2020 Targets) will be difficult to reach in any case. While climate impacts have now been observed with some levels of confidence in some places, it will be difficult to blame climate change for limited progress towards the Millennium Development Targets.

Table 20.7. *The Millennium Development Goals.*

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat HIV/AIDS, malaria and other diseases
7. Ensure environmental sustainability
8. Develop a global partnership for development

Source: http://www.un.org/millenniumgoals/documents.html

In the longer term, Arrow et al. (2004) argue that adaptation decisions can reduce the effective investment available to reach the MDGs. They thereby raise the issue of opportunity costs: perhaps investment in climate adaptation might retard efforts to achieve sustainable development. Because the determinants of adaptive capacity and of sustainable development overlap significantly; however, (see Section 20.2) it is also possible that a dollar spent on climate adaptation could strengthen progress towards sustainable development.

Whether synergistic effects or trade offs will dominate interactions between climate impacts, adaptation decisions and sustainable development decisions depend, at least in part, on the particular decisions that are made. Decisions on how countries will acquire sufficient energy to sustain growing demand will, for example, play crucial roles in determining the sustainability of economic development. If those demands are met by increasing fossil fuel combustion, then amplifying feedbacks to climate change should be expected. There are some indications that this is now occurring. Per capita emissions of CO_2 in developing countries rose from 1.7 tonnes of CO_2 per capita in 1990 to 2.1 tonnes per capita in 2002; they remained, though, far short of the 12.6 tonnes of CO_2 per capita consumed in developed countries (UN, 2005). Resources devoted to expanding fossil fuel generation could, therefore, be seen as a source of expanded climate-change impacts. On the other hand, investments in forestry and agricultural sectors designed to preserve and enhance soil fertility in support of improved food security MDGs (e.g., Goal #1) might have synergies for climate mitigation (through carbon sequestration) and for adaptation (because higher economic returns for local communities could be invested in adaptation). It is simply impossible to tell, *a priori*, which effect will dominate. Each situation must be analysed qualitatively and quantitatively.

These complexities make it clear that not all development paths will be equal with respect to either their consequences for climate change or their consequences for adaptive capacity. Moreover, the Millennium Ecosystem Assessment (MA, 2005) and others (e.g., AfDB et al., 2004) argue that climate change will be a significant hindrance to meeting the MDGs over the long term. There is no discrepancy here because stresses from climate change will grow over time. Some regions and countries are already lagging in their progress towards the MDGs and these tend to be in locations where climate vulnerabilities over the 21st century are likely to be high. For example, the proportion of land area covered by forests fell between 1990 and 2000 in sub-Saharan Africa, South-East Asia and Latin America and the Caribbean, while it appeared to stabilise in developed countries (UN, 2005). Energy use per unit of GDP fell between 1990 and 2002 in both developed and developing regions, but developed regions remained approximately 10% more efficient than developing regions (UN, 2005). In short, regions where ecosystem services and contributions to human well-being are already being eroded by multiple external stresses are more likely to have low adaptive capacity.

20.7.2 Sectoral and regional implications

The range of increase in global mean temperature that could be expected over the next several centuries is highly uncertain. The compounding diversity in the regional patterns of temperature change for selected changes in global mean temperature is depicted elsewhere in IPCC (2007b, Figure SPM.6); so, too, are illustrations of geographic diversity in changes in precipitation and model disagreement about even the sign of this change (IPCC, 2007b, Figure SPM.7). Earlier sections of this chapter have also underscored the difficulty in anticipating the development of adaptive capacity and the ability of communities to take advantage of the incumbent opportunities. Despite all of this complexity, however, it is possible to offer some conclusions about vulnerability across regions and sectors as reported throughout this report.

Locating the anticipated impacts of climate change on a map is perhaps the simplest way to see this point. Figure 9.5, for example, shows the spatial distribution of the projected impacts that are reported for Africa in Chapter 9. The power of maps like this lies in their ability to show how the various manifestations of climate change can be geographically concentrated. It is clear, as a result, that climate change can, by virtue of its multiple dimensions, be its own source of multiple stresses. It follows immediately that vulnerability to climate change can easily be amplified (in the sense that total vulnerability to climate change is greater than the sum of vulnerabilities to specific impacts) in regions like the south-eastern coast of Africa and Madagascar.

Maps of this sort do not, however, capture sensitivities to larger indices of climate change (such as increases in global mean temperature); nor do they not offer any insight into the timing of increased vulnerabilities.

Tables 20.8 and 20.9 address these deficiencies by summarising estimated impacts at global and regional scales against a range of changes in global average temperature. Each entry is drawn from earlier chapters in this report, and assessed levels of confidence are indicated. The entries have been selected by authors of the chapters and the selection is intended to illustrate impacts that are important for human welfare. The criteria for judging this importance include the magnitude, rate, timing and persistence/irreversibility of impacts, and the capacity to adapt to them. Where possible, the entries give an indication of impact trend and its quantitative level. In a few cases, quantitative measures of impact have now been estimated for different amounts of climate change, thus pointing toward different levels of the same impact that might be avoided by not exceeding given amounts of global temperature change.

The time dimension is captured by the bars drawn at the top of Table 20.8; they indicate the range of global average temperature increase that could be expected during the 2020s, the 2050s and the 2080s among the SRES collection of unmitigated scenarios as well as a range of alternative stabilisation pathways (Nakićenović and Swart, 2000). The real message to be drawn from their inclusion is that no temperature threshold associated with any subjective judgment of what might constitute 'dangerous' climate change can be guaranteed by anything but the most stringent of mitigation interventions, at least not on the basis of current knowledge. Moreover, there is an estimated commitment to warming of 0.6°C due to past emissions, from which impacts must be expected, regardless of any future efforts to reduce emissions in the future.

20.7.3 The complementarity roles of mitigation and enhanced adaptive capacity

IPCC (2001a) focused minimal attention on the co-benefits of mitigation and adaptation, but this report has added a chapter-length assessment of current knowledge at the nexus of adaptation and mitigation. An emphasis on constructing a "portfolio of adaptation and mitigation actions" has emerged (Chapter 18, Sections 18.4 and 18.7). Moreover, the capacities to respond in either dimension are supported by 'similar sets of factors' (Chapter 18, Section 18.6). These factors are, of course, themselves determined by underlying socio-economic and technological development paths that are location and time specific.

Yohe et al. (2006a, b) offer suggestive illustrations of potential synergies within the adaptation/mitigation portfolio; complementarity in the economic sense that one makes the other more productive. Figures 20.5 and 20.6 display the geographic distribution of these synergies in terms of a national vulnerability index with and without mitigation, and with and without enhanced adaptive capacity by 2050 and 2100, respectively. Vulnerabilities that were assigned to specific countries on the basis of a vulnerability index derived from national estimates of adaptive capacity provided by Brenkert and Malone (2005) and the geographic distribution of temperature change derived from a small ensemble of global circulation models. The upper left panels of Figures 20.5 and 20.6 present geographical distributions of vulnerability in 2050 and 2100, respectively, along the SRES A2 emissions scenario with a climate sensitivity of 5.5°C under the limiting assumption that adaptive capacities are fixed at current levels; global mean temperature climbs by 1.6°C and 4.9°C above 1990 levels by 2050 and 2100, respectively. These two panels are benchmarks of maximum vulnerability against which other options can be assessed. Notice that most of Africa plus China display the largest vulnerabilities in 2050 and that nearly every nation displays extreme vulnerability by 2100. A2 was chosen for illustrative clarity with reference to temperature change only. Moreover, none of the interpretations depend on the underlying storyline of the A2 scenario; Yohe et al. (2006b) describes comparable results for other scenarios.

The upper right panels present comparable geographic distributions under the assumption that adaptive capacity improves everywhere with special emphasis on developing countries; their capacities are assumed to advance to the current global mean by 2050 and 2100 for Figures 20.5 and 20.6,

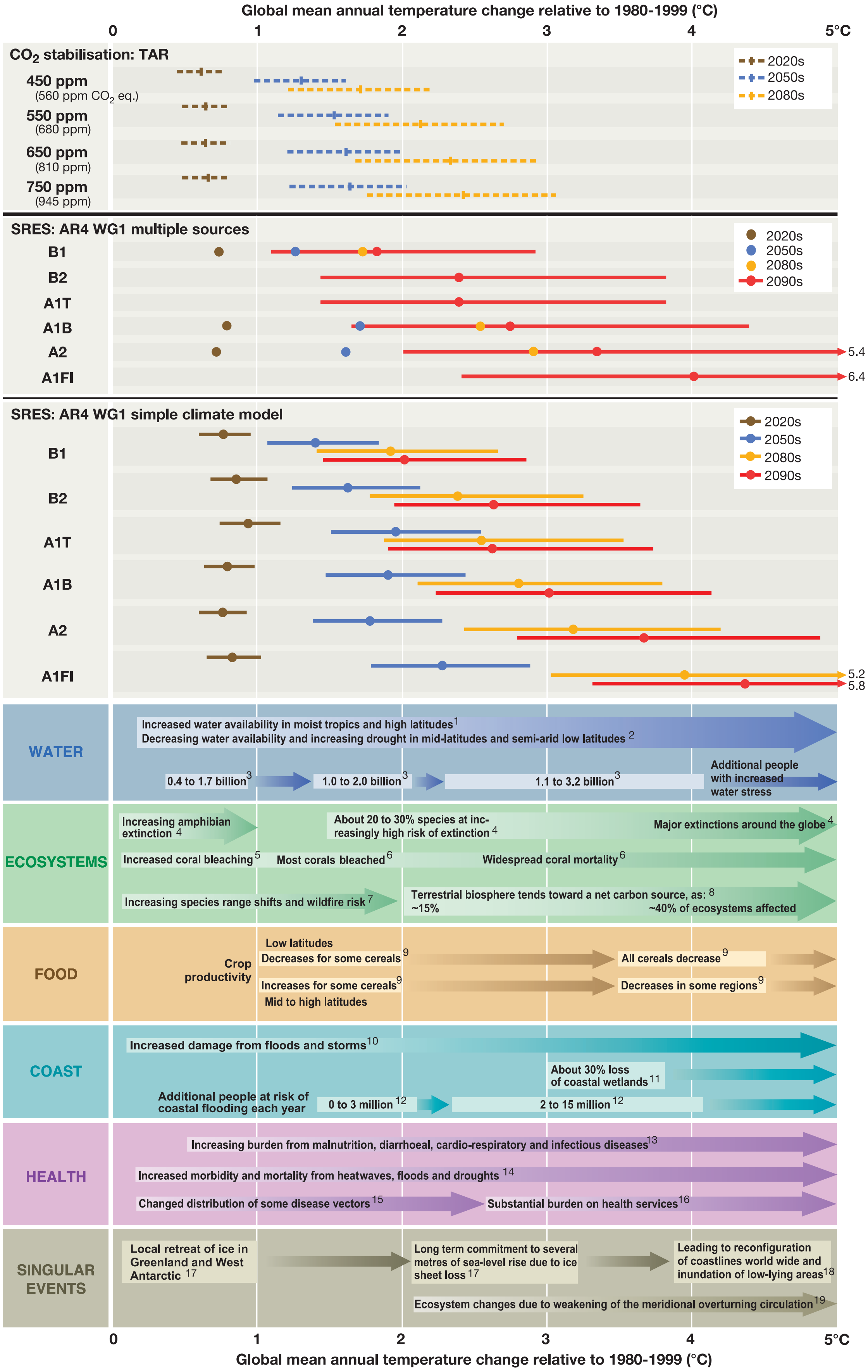


Table 20.8. *Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. This is a selection of some estimates currently available. All entries are from published studies in the chapters of the Assessment. (Continues below Table 20.9)*