Chapter 19. Emergent Risks and Key Vulnerabilities

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Executive Summary

A focal point of this chapter is the interaction of the changing physical characteristics of the climate system with evolving characteristics of socioeconomic and biological systems (exposure and vulnerability) to produce risk.

Key risks arise from high probability of occurrence of a substantial physical impact of climate change or a high degree of exposure and vulnerability to an impact, or both.

Emergent risks are risks which have only recently emerged in the scientific literature in sufficient detail to permit assessment and which have the potential to become *key risks* as additional understanding accumulates, i.e. those relevant to interpreting Article 2 of the UN Framework Convention on Climate Change (UNFCCC).

Key vulnerabilities arise in systems due to one or more of the following characteristics: exposure to physical climate changes, probability of major harm due to exposure, importance of exposed system, limited ability to cope with impacts, limited adaptation capacity, persistence of conditions of high susceptibility to climate stressors, cumulative and interactive stresses.

Existing frameworks, such as Reasons for Concern and Key Vulnerabilities, for evaluating risks pertinent to Article 2 of the UNFCCC are updated here in light of the advances in SREX and the current report's discussions of vulnerability, human security, and adaptation.

Alternative development paths influence risk by changing both the likelihood of physical impacts (through their effect on greenhouse gas emissions) and by altering vulnerability and exposure.

Interactions among climate change impacts in various sectors and regions, and between these impacts and human adaptation in other sectors and regions, as well as interactions between adaptation and mitigation actions, are generally not included, or not well integrated, into projections of climate change impacts. These interactions create emergent risks and/or key vulnerabilities not previously recognized.

Among these are interactions of climate change with other non-climate factors such as land management, water management, air pollution (which has drivers in common with climate change), energy production (including cultivation of biofuel feed stocks) and diseases.

A key interaction is that between the impacts of climate change on biodiversity and the impacts of climate change on human systems, where the effects on human systems are increased by the loss of ecosystem services that biodiversity provides such as water and air purification, protection from extreme weather events, preservation of soils, recycling of nutrients, and pollination of crops.

Spatial convergence of impacts in different sectors can create impact 'hotspots' involving new interactions.

Adaptation designed for one sector interacting with functioning of another sector can create risks (e.g. increasing irrigation to crops in response to a drying climate can exacerbate water stress in downstream areas such as wetlands, in cases where the latter provide important water cleaning services)

Risks emerge from indirect, trans-boundary, and long-distance impacts of climate change acting on agricultural and energy sectors among others. Impacts of climate change may be transmitted by human responses such as migration and via global markets. An emergent risk is the association of climate change, acting through uncertain channels, with conflict.

Other emergent risks relate to ocean acidification, geo-engineering, temperature increases above 4^0C, and indirect health impacts of high ambient concentrations of CO_2.

A large number of key vulnerabilities, key risks, and emergent risks follow from the assessments of individual chapters of this report. Many of these reflect differential vulnerability between groups due to age, wealth, or income status, and deficiencies in governance.

In updating and revising the Reasons for Concern framework, we find that since AR4, there is new and stronger evidence to support the previous judgment of *high confidence* that "a warming of up to 2°C above 1990-2000 levels would result in significant impacts on many unique and vulnerable systems, and would likely increase the endangered status of many threatened species, with increasing adverse impacts (and increasing confidence in this conclusion) at higher temperatures".

Based largely on the findings from SREX, we assess that the overall risk from physical climate characteristics of extreme events has not changed significantly since AR4. However, there is a new appreciation for the importance of exposure and vulnerability, in both developed and developing countries.

New methods for estimating aggregate impacts have emerged. Consistent with AR4, we judge that there remains *high confidence* that globally aggregated figures underestimate damages because they cannot include many non-quantifiable impacts and there is *very high confidence* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations.

The determination of key risks as reflected, for example, in the Reasons for Concern has not previously been distinguished across alternative development pathways. The development of risk profiles from Shared Socioeconomic Pathways and Representative Concentration Pathways is an important area of research that can lead to improvement in the framework developed in this chapter.

New methods of estimating the impacts of climate change that may be avoided by mitigation of greenhouse gas emissions have been developed. These show that the avoided impacts are potentially large and increasing over the 21st century. Benefits from mitigation are most immediate for ocean acidification, and least immediate for impacts related to sea level rise.

Mitigation and adaptation possibilities are not unlimited, implying that some degree of risk from residual damages will be unavoidable. For example, no model-based scenarios in the literature demonstrate the feasibility of limiting warming to a maximum of 1.5 C with at least 50% likelihood.

The design of risk-management strategies could be informed by observation and projection systems that would provide an actionable early warning signal of an approaching threshold response. However, there is *low confidence* in the feasibility and requirements for such systems since studies to date have been highly simplified and limited in number.

19.1. Purpose, Scope, and Structure of the Chapter

The objective of this chapter is to assess new literature published since the Fourth Assessment Report on emergent risks and key vulnerabilities to climate change from the perspective of the distribution of risk over geographic location, economic sector, time period, and socioeconomic characteristics of individuals and societies. Frameworks used in previous IPCC reports to assess risk in the context of Article 2 of the UN Framework Convention on Climate Change (UNFCCC) are updated and extended in light of new literature; and additional frameworks arising in recent literature are examined. A focal point of this chapter is the interaction of the changing physical characteristics of the climate system with evolving characteristics of socioeconomic and biological systems (exposure and vulnerability) to produce risk (see Figure 19-1).

[INSERT FIGURE 19-1 HERE
Figure19-1: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. The figure visualizes the different terms and concepts discussed in this chapter. It underscores that risks are a product of a complex interaction between physical impacts due to climate change and climate variability on the one hand and the vulnerability of a society or a social-ecological system and its exposure to climate-related hazards on the other. DRR means disaster risk reduction and CAA indicates climate change adaptation. The definition and use of "key" are indicated in Box 19-2 and the glossary. Vulnerability, as the figure shows, is largely the result of socio-economic development pathways and societal conditions. Both the changes in the climate system (left side) and the development processes (right side) are key drivers of the different core components (vulnerability, exposure, and physical impacts or hazards) that constitute risk (modified version of Figure 1, IPCC 2012).]

19.1.1. Historical Development of this Chapter

The Third and Fourth Assessment Reports (TAR and AR4, respectively) each devoted chapters to evaluating the state of knowledge relevant to Article 2 of the UNFCCC (Smith et al 2001, Schneider et al 2007; see Box 19-1). The TAR sorted and aggregated impacts discussed in the literature according to a framework called *Reasons for Concern* (RFCs), and assessed the level of risk associated with individual impacts of climate change as well as each category or "reason" as a whole, generally as a function of global mean warming. This assessment took account of the distribution of vulnerability across particular regions, countries, and sectors. AR4 furthered the discussion relevant to Article 2 by assessing new literature and developing criteria which might be used by policy makers for determining which impacts and vulnerabilities were *key*, i.e., meriting particular attention in respect to Article 2 (see Box 19-2 for definitions of Reasons for Concern and Key Vulnerabilities [KVs]). AR4 emphasized the differences in vulnerability between developed and developing countries but also assessed emerging literature describing vulnerability pertaining to various aggregations of people (such as by ethnic, cultural, age, gender, or income status) and response strategies for avoiding key impacts. The Reasons for Concern were updated and the Synthesis Report (IPCC 2007) noted that they "remain a viable framework to consider key vulnerabilities". However, their utility was limited by several factors: the lack of a time dimension (i.e., representation of impacts arising from timing and rates of climate change and climate forcing), the focus on risk only as a function of global mean temperature, lack of a clear distinction between impacts and vulnerability, and importantly, incomplete incorporation of the socioeconomic context, particularly adaptation capacity, in representing impacts and vulnerability.

19.1.2. The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)

SREX (IPCC 2011) provides additional insights with respect to the fourth "reason" (the risk of extreme weather events) and particularly the distribution of capacities to adapt to such events between countries, communities, and other groups, and the limitations of implementation of these capacities. SREX emphasized the role of the socioeconomic setting and development pathway (expressed through exposure and vulnerability) in determining, on the one hand, the circumstances where extreme events do or do not result in extreme impacts and disasters, and on the other hand, when non-extreme events may also result in extreme impacts and disasters.

19.1.3. New Developments in this Chapter

With these frameworks already established, and a long list of impacts and key vulnerabilities enumerated and categorized in previous assessments, the current chapter has three main objectives: first, to recognize the dynamic nature of our understanding by assessing *emergent risks* (see Box 19-2), i.e., those which have only recently emerged in the scientific literature in sufficient detail to permit assessment and which have the potential to become relevant to interpreting Article 2 as additional understanding accumulates. For example, since AR4, sufficient literature has emerged to allow initial assessment of the relationship between climate change and conflict. The second objective is to reassess and reorganize the existing frameworks (based on Reasons for Concern and Key Vulnerabilities) for evaluating the literature pertinent to Article 2 of the UNFCCC in order to address the deficiencies cited in section 19.1.1, particularly in light of the advances in SREX and the current report's discussions of vulnerability and human security (see chapters 12 and 13) and adaptation (see chapters 14-17 and 20). From this perspective, the objective stated in Article 2 may be viewed as aiming in part to ensure human security in the face of climate change. Thirdly, this chapter will assess recent literature pertinent to additional frameworks for categorizing risk and vulnerability, particularly focusing on indirect impacts and interaction and concatenation of risk, including geographic "hotspots" (see 19.3).

In order to clarify the relative roles of characteristics of the physical climate system, like increases in temperatures, precipitation, or storm frequency, and characteristics of the socioeconomic and biological systems with which these interact (vulnerability and exposure) to produce risks of consequences, we rely heavily on a concept used sparingly in the TAR and AR4, *key risks* (see Box 19-2). Furthermore, we emphasize recent literature pointing to the *dynamic* character of vulnerability based on its intimate relationship to development.

We consider a variety of types of emergent risks, including for example, vulnerability to impacts arising from multiple interacting systems and stresses, indirect impacts, trans-boundary impacts, and impacts over longer distances. To cite one example which illustrates all of these properties, consider that climate impacts on agriculture, water availability, and sea level may be a contributing cause for the migration of populations. These shifts entail both risks and potential benefits for the migrants, for the regions where they originate, and for the destination regions (see 19.5.2.1 and 12.4). Risks include indirect impacts occurring at the new locations of settlement, which may be near the location of the original impact or quite distant. Such distant, indirect effects would compound the direct consequences of climate change at the locations receiving the incoming populations, and involve multiple physical and biological systems which interact, including impacts on ecosystems and species at the receiving locations which are subject simultaneously to climate changes and consequences of an increased population.

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Box 19-1. Article 2 of the UNFCCC and the Copenhagen Accord

Article 2

OBJECTIVE
The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

Copenhagen Accord (excerpt)

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.

_____ END BOX 19-1 HERE ____

____ START BOX 19-2 HERE ____

Box 19-2. Definitions

Impacts - Effects on natural and human systems. In this report, the term ‘impacts’ is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.

Vulnerability - The propensity or predisposition to be adversely affected.

Risk - The potential for adverse effects on lives, livelihoods, health status, economic, social and cultural assets, services (including environmental) and infrastructure due to particular hazardous events occurring within some specified time period (IPCC 2012). More generally, risk refers to a situation or an event where something of human value (including humans themselves) is at stake and where the outcome is uncertain (chapter 2).

Expressed formally, Risk = (Probability of an Impact) X (Consequences)

Key impact - An impact relevant to the definition and elaboration of “dangerous anthropogenic interference (DAI) with the climate system,” in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2, meriting particular attention by policy makers in that context.

Key risk - A risk that is relevant to the definition and elaboration of “dangerous anthropogenic interference (DAI) with the climate system,” in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2, meriting particular attention by policy makers in that context. Key risks are potential adverse effects on humans and social-ecological systems due to the interaction of climate-related physical impacts with vulnerabilities of societies exposed. Risks are considered “key” due to high physical impact or high vulnerability of societies exposed, or both.

Key vulnerability - A vulnerability that is relevant to the definition and elaboration of “dangerous anthropogenic interference (DAI) with the climate system,” in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2, meriting particular attention by policy makers in that context. Vulnerabilities are considered “key” if they have the potential to combine with physical impacts to result in severe consequences for society or social-ecological systems. Vulnerabilities that have little influence on risk would not be considered key.

Extract from Chapter 19, WGII, AR4:

Many impacts, vulnerabilities and risks merit particular attention by policy-makers due to characteristics that might make them ‘key’. The identification of potential key vulnerabilities is intended to provide guidance to decision-makers for identifying levels and rates of climate change that may be associated with ‘dangerous anthropogenic interference’ (DAI) with the climate system, in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2 (see Box 19-1). Ultimately, the definition of DAI cannot be based on scientific arguments alone, but involves other judgments informed by the state of scientific knowledge.

Emergent risk - A risk that has only recently emerged in the scientific literature in sufficient detail to permit assessment, for example the hypothetical impacts of geoengineering (solar radiation management) on the monsoon or the effect of climate change on conflict, and that has the potential to become a key risk once sufficient understanding of it accumulates. Risks emerge in the scientific literature over time for a number of reasons, including that their initial consequences have only recently been detected above the natural variability of the climate system, for example certain effects of ocean acidification on calcareous organisms; or because the risks arise from the interaction of phenomena in a complex system, for example the effect of human population shifts in response to climate change on the capacity of receiving regions to adapt to local climate changes.

Reasons for Concern – Elements of a classification framework, first developed in the IPCC Third Assessment Report, which aims to facilitate judgments about what level of climate change may be “dangerous” (in the language of Article 2 of the UNFCCC) by aggregating impacts, risks, and vulnerabilities.

Summary of Reasons for Concern, Chapter 19, WGII, TAR:

“Reasons for Concern” may aid readers in making their own determination about what is a “dangerous” climate change. Each reason for concern is consistent with a paradigm that can be used by itself or in combination with other paradigms to help determine what level of climate change is dangerous. The reasons for concerns are the relations between global mean temperature increase and:

1. *Damage to or irreparable loss of unique and threatened systems*
2. *The distribution of impacts*
3. *Global aggregate damages*
4. *The probability of extreme weather events*
5. *The probability of large-scale singular events*

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19.2. Framework for Identifying Key Vulnerabilities, Key Risks, and Emergent Risks

19.2.1. Risk and Vulnerability

Definitions and frameworks that systematize physical impacts, exposure, vulnerability, risk and adaptation in the context of climate change are multiple, overlapping, and often contested (see e.g. Füssel and Klein 2006; IPCC 2007; UN/ISDR 2004, Birkmann 2006a; ICSU-LAC 2010a,b, Cardona 2011; Burton et al., 1983; Blaikie et al., 1994; Twigg, 2001, Turner et al., 2003a, b; Schröter et al., 2005; Adger 2006; 2006; Villagran, 2006; Cutter et al., 2008; Cutter and Finch, 2008. Thomalla et al. 2006; Tol and Yohe 2006; IPCC 2012); however, most of the concepts and the respective literature differentiates between vulnerability, risk, impacts and hazards (see e.g. IPCC 2012). The following section serves not solely as an update of existing knowledge about key vulnerabilities and key risks since the AR4, but also provides a more coherent framework to systematize these concepts and to enhance the understanding of these phenomena based on new literature, including SREX (IPCC 2012).

The large body of literature on climate change adaptation and risk reduction as well as loss and damage indicates that risk in the context of climate change, such as risks related to human health and well-being arising from droughts or heat waves or potential economic losses due to sea level rise, are not solely externally generated circumstances to which societies respond, but rather, the results of complex interactions among societies or communities, ecosystems, and physical impacts arising from climate change (IPCC 2012; Susman et al. 1983; Comfort et al. 1999, Birkmann et al. 2011,UN/ISDR 2011). In this chapter, risk describes the potential outcome of the interaction of vulnerable conditions of societies and social-ecological systems (arising from multiple stresses such as poverty and marginalization which limit their ability to cope and adapt) with climate changes to which they are exposed and the resulting physical impacts (e.g. changes in weather related extreme events triggering hazards such as heat waves, droughts, and wildfires; see Figure 19-1). The concept of risk encompasses the probability of the occurrence of specific physical impacts (hazard or stressor factor; see IPCC 2012), and the consequences of their occurrence in terms of harm, loss and disruption to human lives and social-ecological systems (vulnerability factor). The diverse approaches to vulnerability encompass the concepts of susceptibility or sensitivity, and societal response capacities including adaptive capacity (e.g. Füssel and Klein 2006; UN/ISDR 2004, Birkmann 2006a; Cardona 2011; Blaikie et al., 1994; Turner et al., 2003a, b; Adger 2006; Villagran, 2006; Cutter et al., 2008; Cutter and Finch, 2008; IPCC 2012).

We define the direct consequences of climate change as physical impacts, such as deglaciation, ocean circulation changes, ice sheet disintegration, etc. Hence, vulnerability refers primarily to characteristics of human or social-ecological systems exposed to climate change and respective single or multiple hazards (UNDRO, 1980; Cardona, 1986, 1990; Liverman, 1990; Cannon 1994, 2006; Blaikie *et al.,* 1996; UNISDR, 2004, 2009; Birkmann, 2006b, Thywissen, 2006, Füssel and Klein 2006 and IPCC SREX 2011). Ecosystems or geographic areas can be classified as vulnerable, especially if vulnerability of humans arises from impacts on the related ecosystem services (see Renaud 2011) or if these systems embody important values (e.g. cultural values), in which case their disappearance might increase the vulnerability of a society, a community or a social-ecological system. The Millennium Ecosystem Assessment (MEA) for example identified ecosystem services that probably affect the vulnerability of societies and communities, such as provision of fresh water resources and air quality (see in detail MEA 2005)

Compared to the AR4 which did not fully differentiate key vulnerabilities, impacts and risks, the new conceptualization used here provides a more coherent and precise framework to systematize vulnerability, risk, hazard, and physical impacts (see Figure 19-1). In addition, the framework underscores that the development process of a society has significant implications for a) the anthropogenic induced climate change in terms of greenhouse gas emissions, as well as b) for the vulnerability patterns and their severity as well as for the exposure of societies to the physical impacts. In this regard it is important to emphasize that climate change is not a risk per se; rather physical impacts arising from climate change in combination with the vulnerability of a system exposed determine the level of risk. Identifying key vulnerabilities therefore also facilitates estimating key risks when coupled with information about the climate and climate change. Consequently, it is often not possible to attribute a particular outcome or set of consequences to a single physical impact of climate. The societal determination of risk related to climate change has two aspects: anthropogenic climate change and respective physical impacts; and societal responses to these physical impacts (and the limits of responses, from which vulnerabilities arise) as well as anticipatory actions. This differentiation provides the basis for criteria developed in this chapter for assessing vulnerability and risk.

19.2.2. Criteria for Identifying Key Vulnerabilities and Key Risks

Vulnerability is dynamic and context specific, determined by human behavior and societal organization, which influences the levels of exposure (e.g. urbanization of low laying areas) and susceptibility of people (e.g. marginalization) and livelihoods exposed, taking into account their response capacity (coping and adaptive capacities) (see IPCC 2012). Furthermore, human perceptions and cognitive constructs about risks and adaptation options as well as cultural contexts influence adaptive capacities and decision making processes and consequently influence vulnerability of societies to climate change (e.g. Kuruppu/Liverman 2011; Grothmann/Patt 2005; Rohmberg 2009; see section 19.4.2.3). Additionally, IPCC SREX stressed that consideration of multiple dimensions (e.g., social, economic, environmental, institutional, cultural) as well as different causal factors can improve strategies to reduce vulnerability to climate change (see IPCC 2012, p. 17, 67-106).

Key vulnerability and key risk are defined in Box 19-2. Vulnerability cannot be considered “key” if the different factors that determine vulnerability would have negligible influence on the consequences physical impacts would have on societies, social groups, or social-ecological systems. Hence, vulnerabilities that have little influence on the overall risk would not be considered key.

Similarly, the magnitude or other characteristics of the geophysical changes, such as glacier melting or sea level rise, are not by themselves adequate to determine key risks, since the consequences of climate change will be determined largely by the vulnerability of the exposed society or the exposed social-ecological system. Key vulnerabilities and key risks embody a normative component because different societies might rank the various vulnerability and risk factors and actual or potential types of loss and damage differently (see e.g. IPCC 2012, p. 45; IPCC 2007, p. 785).

Recent literature shows that vulnerability profiles as well as loss and damage types assume different dimensions and themes for different regions, country groups and social groups (see e.g. Surminski et al. 2012). Generally, vulnerability merits particular attention when the survival of communities or societies is threatened (see e.g. UN/ISDR 2011; Birkmann et al. 2011).

Climate change will influence both the nature of the climatic stressors societies and ecosystems are exposed to and also contribute to deterioration or improvement of coping and adaptive capacities of systems exposed to these changes. Consequently, many studies (Cardona 2010, Birkmann et al. 2011, Wisner et al. 2004) focus with a priority on the vulnerability of humans and societies as a key feature, rather than on the first order physical impact or the geophysical changes.

19.2.2.1. Criteria for Identifying Key Vulnerabilities

AR4 WGII Ch. 19 highlighted seven criteria that may be used to identify key vulnerabilities: Here we reorganize and further develop these criteria in order to improve the differentiation between key vulnerabilities, key risks and physical impacts – taking into account recent literature (IPCC 2012; UN/ISDR 2011, Birkmann 2006a; ICSU-LAC 2010a,b, Cardona 2011; Blaikie et al., 1994; Turner et al., 2003a, b; Villagran, 2006; Cutter et al., 2008; Cutter and Finch, 2008; Bohle 2001). The criteria for identifying vulnerabilities as “key” used in the AR4 are: magnitude of impacts, timing of impacts, persistence and reversibility of impacts, likelihood (estimates of uncertainty) of impacts and vulnerabilities and confidence in those estimates, potential for adaptation, distributional aspects of impacts and vulnerabilities, and importance of the system(s) at risk. These criteria do not provide a systematic differentiation of vulnerability and risk.

Revised criteria for assessing *key vulnerabilities* used here should provide an improved basis to distinguish between changes in the physical climate and associated physical impacts (like sea level rise), vulnerability and risk for societies or social-ecological systems. The following seven criteria are used to judge whether vulnerabilities are key:

1) *Exposure of a society, community, or social-ecological system to climatic stressors*. While exposure is defined here separately from vulnerability, exposure is an important precondition for considering a specific vulnerability as key. If a system is not at present nor in future exposed to climatic stressors, it is less important to consider its vulnerability to such stressors. The exposure to climatic stressors can be assessed in its spatial and temporal dimensions.
2) *Probability that societies or social-ecological systems exposed to a climatic stressor or physical impact would experience major harm, loss and damages*. Vulnerability is considered key when there is a high probability that a climatic stressor, often in combination with non-climatic stressors, would cause major harm to an exposed and particularly susceptible societal or social-ecological system. This criterion can be made specific with relative vulnerability assessment of societies, regions, and groups (one region or society or group within these may be more vulnerable than another). For example sea-level rise will impact coastal communities and regions worldwide; however, groups, communities and regions most vulnerable are those that have a high susceptibility and a low capacity to cope and adapt to these influences. In this regard recent literature indicates that low-lying areas and communities in developing countries with limited resources to adapt and a low awareness about climatic stressors are more vulnerable than regions and communities in highly developed countries that can afford the further strengthening of coastal protection systems that reduce the negative consequences of sea-level rise (Nicholls and Small 2002; Klein et al. 2003, p. 109). Criteria that might be used to assess such susceptibilities or sensitivities encompass among other factors poverty and wealth status, demographic characteristics, and aspects of governance (see IPCC 2012, p. 70-74 and chapter 12 of this report), such as failed states or violent conflicts. A focus on relative vulnerability is highly important to improve the knowledge base for adaptation needs.
3) *Importance of the system(s) which is vulnerable*. Various societies and people in different regions and cultural contexts view the importance of systems, impacts, and services differently. However, the identification of key vulnerabilities is less subjective when it involves those systems that are crucial for the survival of societies and the important ecosystem services on which societies depend. The importance of certain ecosystem services for example varies with geography and landscape as well as the specific livelihoods dependent upon them. For example, drought exposed farmer households in the Sahel are heavily depending on ecosystem services such as water and fertile soils.
4) *Limited ability of societies or communities to cope with the stressor within existing capacities*. Coping refers primarily to capacities that are available here and now to reduce the negative impacts of climatic stress on communities or social-ecological systems exposed. Coping is part of the formula that determines vulnerability at any one moment in time. Coping also connotes the protection of the current system and institutional settings (see Birkmann, 2011) rather than improving these to increase capacities against climate risks (IPCC 2012, p. 51). Limits of coping provide a criterion for key vulnerabilities.
5) *Limited ability of societies to build adaptive capacities to reduce or limit vulnerability as environmental and climate conditions change*. The capacity of societies (including communities) to build adaptive capacities is a central issue when assessing vulnerability (IPCC 2007, AR4). Adaptation is a continuous process, with levels of adaptive capacity changing over time. Adaptation in contrast to coping denotes a longer-term and constantly unfolding process of learning, experimentation and change that alters vulnerability. Adaptation is more strategic and long-term compared to coping. It includes acting to shape all aspects of vulnerability and is manifest through the systems and outcomes of learning – planned and spontaneous, pre- and post-disaster (Pelling, 2010; Smit et al. 1999; Smit and Wandel 2006; Pielke 1998; Frankhauser et al. 1999; Adger et al. 2005; Smithers and Smit 1997). This understanding of adaptation is commensurate with the emerging consensus from climate change literature (see Kelly and Adger, 2000; Yohe and Tol, 2002; Pelling, 2010) where coping describes actions taken within existing constraints (including vision and knowledge), while adaptation signifies expanding the boundaries of those constraints, for instance, through institutional changes (Pelling et al. 2008; Tschakert and Dietrich 2012; Garschagen 2011).
6) *Persistence of vulnerable conditions and degree of irreversibility of consequences*. Vulnerabilities are considered key when they are persistent and difficult to alter as well as having a high potential to interact with a hazardous event to produce irreversible negative changes. This is particularly the case when the

vulnerability is high and the capacities to cope or adapt are low. In this way, social-ecological systems (coastal communities dependent on fishing or mountain communities dependent on specific soil conditions) may reach a tipping point that would cause a partial or full collapse of the system (see Renaud et al. 2010).

7) *Presence of conditions that make societies highly susceptible or sensitive to cumulative stressors in multiply-interacting systems*. Communities or social groups as well as social-ecological systems existing under conditions that make them highly susceptible to additional climate stressors or that limit their ability to cope and adapt, such as chronic poverty or living in a failed state (e.g. drought disaster in Somalia) should be taken into account. In addition, inability to replace a system or compensate for potential and actual losses and damages are criteria for judging vulnerabilities as key. Defining key vulnerabilities regarding various societal groups (as above in criterion #2), or ecosystem services takes into account the contextual conditions that make these societies or exposed elements or groups highly vulnerable. Consequently, the vulnerability to cumulative stressors and vulnerability of multiple-interacting systems is not solely determined by the susceptibility of individual systems or groups to the direct physical impacts or climatic stressor, but is a matter of joint susceptibility, taking into consideration feedbacks among coping and adaptive capacity, climate change and development pathways – thus the wider enabling or non-enabling context of conditions (O'Brien et al. 2004; Leichenko and O'Brien 2008).

19.2.2.2. Criteria for Identifying Key Risks

Key risks are the product of the interaction of climate-related physical impacts (e.g. impacts on water resources due to glacier melting, heatwaves, changes in flood regimes, etc.) with key vulnerabilities of exposed societies and communities (high level of poverty, limited coping and adaptive capacities etc.). A risk would not be considered "key" if the climatic stressor or physical impact had a low probability and magnitude and would impact a society, community or a social-ecological system with low vulnerability.

In contrast to the criteria for identifying key vulnerabilities, the criteria for identifying key risks take into account the magnitude, frequency and severity of the physical impacts (or hazards) linked to climatic changes. The following four criteria are used to judge whether risks are key:

1) *Magnitude:* Risk are key if judged to have large magnitude, determined by a variety of metrics including human mortality and morbidity, economic loss, cultural importance, and distributional consequences (see Schneider et al 2007; IPCC 2012, Below 2009).
2) *Likelihood that risks will materialize, and their timing*. Risks are considered key when there is a high probability that the physical impact or hazard due to climate change will occur under circumstances where societies or social-ecological systems exposed to these physical impacts have very limited capacities to cope or adapt to these stressors . Risks which materialize in the near term may be evaluated differently than risks which materialize in the distant future, since the time available for building up adaptive capacities is different (Oppenheimer 2005; Schneider et al 2007).
3) *Irreversibility and persistence of conditions and drivers that determine risks*. Risks are considered key when there is a high probability that they would involve irreversible harm, losses and damages. In addition, the persistence of risks refers to the fact that underlying drivers and conditions of these risks cannot be rapidly reduced (i.e., due to lags in the physical system resulting from e.g., the long atmospheric residence time of CO2), or the damage to societal and social-ecological systems cannot be quickly reversed (see point 6 above). Critical infrastructures, such as electric power, communications, and transport networks in developed countries often embody systemic risks due to their interdependencies as well as due to the fact that many basic processes in industrialized countries and countries in transition are dependent on the availability and functioning of these critical infrastructures. Risk to such systmes may indicate key vulnerabilities.
4) *Limited ability to reduce the magnitude and frequency or nature of physical impacts and the vulnerability of societies and social-ecological systems exposed*. Risks are considered to be key when societies have very limited means through development (either by reducing emissions of greenhouse gases or improving coping and adaptation) to reduce the magnitude, frequency or intensity of physical impacts and their consequences for society and social-ecological systems.

19.2.3. Criteria for Identifying Emergent Risks

Emergent risks are those risks which have only recently emerged in the scientific literature in sufficient detail to permit assessment and which has the potential to become a key risk as additional understanding accumulates (see Box 19-2). Risks emerge in the scientific literature over time for a number of reasons, including that their initial consequences have only recently been detected above the natural variability of the climate system or because the risks arise from the interaction of phenomena in a complex system, for example those involving unforeseen feedback and response processes between climatic change, human interventions and feedback processes in natural systems; or new vector borne diseases or those diseases arising from partial break down of critical infrastructures, such as sewage systems that do not function properly. Emergent risks could also be linked to the increasing urbanization of low laying coastal areas that are prone to sea-level rise or the phenomena that new flooding risk emerges due to urbanization of vulnerable areas not historically populated.

Overall, the above differentiation of physical impacts due to climate change, key vulnerabilities, and key risks allows an improved systematization of the different issues and factors that would be considered in the context of development of adaptation strategies as well as the implementation of Article 2 of the UNFCCC in terms of the development of mitigation strategies.

Section 19.6.1 and the table therein presents examples of the application of the framework developed here, based on judgments made by the authors of many of the chapters of this report.

19.2.4. Identifying Key and Emergent Risks under Alternative Development Pathways

Key risks are determined by the interaction of physical impacts of climate change with vulnerabilities of societies or ecosystems. Future impacts and vulnerabilities will depend in part on underlying socio-economic conditions, which can differ widely across alternative future development pathways (Hallegatte et al., 2011). Therefore some risks could be judged to be key under some development pathways but not others. Similarly, emergent risks, as risks that have only recently emerged sufficiently in the scientific literature to permit assessment, can depend on development pathways as well, since their identification as potentially key risks may be contingent on future socio-economic conditions.

Development pathways will influence the likelihood and nature of physical impacts through their effects on emissions and other forcing such as land use change, and consequently on climate change (see Ch. 12, WG1). Components of development pathways such as economic growth, technical change, and policy will influence the rates and spatial distributions of emissions of greenhouse gases and aerosols, and of land use change (Ch. 5, WG3). As a consequence, different development pathways will lead to different key risks because they affect the magnitude, timing, and heterogeneity of physical impacts of climate change.

Development pathways will also influence the factors involved in identifying key vulnerabilities of human and ecological systems, including both susceptibility to impacts and adaptive capacity (Hallegatte et al., 2011; Fuessel and Klein, 2006; Yohe and Tol, 2002). The size or scale of populations, ecosystems, or economic sectors that are vulnerable to particular impacts will depend on population growth and spatial distribution, economic development patterns, and social systems. Which elements of the human-environment system are most exposed and sensitive to climate hazards, and which are considered most important, will depend on spatial development patterns as well as on cultural preferences, attitudes toward nature/biodiversity, and dependence on climate-sensitive resources or services, among other factors (Adger, 2006; Fuessel, 2009). The geographic or socio-economic heterogeneity of populations, and therefore the potential for distributional consequences, will be affected, as will the degree to which persistent or difficult to reverse vulnerabilities are built into social systems (Adger et al., 2009).

19.2.5. Assessing Key Vulnerabilities and Emergent Risks

The criteria above for assessing vulnerability and risk provide a sequence of potential assessment steps. While the first assessment phase would explore whether and how a society or social-ecological system is exposed to climate related physical impacts and hazards, the assessment thereafter would focus on the probability of loss and harm in case an event or events would affect a society or social-ecological system exposed. In addition, the importance of the system at risk and the ability of a society or system to cope and to adapt to these stressors would be assessed. Finally, the application of the criteria would also require the assessment of the irreversibility of the consequences, the persistence of vulnerable conditions as well as the presence of conditions that make societies susceptible. Hence, the assessment criteria focus on the inner conditions of an individual social-ecological system or community (intrinsic factors) exposed as well as on the contextual conditions that influence the vulnerability of the respective community or social-ecological system. The application of the criteria to identify key risks requires additionally the consideration of the physical impacts and respective hazards together with the key vulnerabilities. Examples of such key vulnerabilities and key risks drawn from other chapters of this assessment are provided in section 19.6. Further operationalizing would be facilitated by consideration of criteria relevant to specific conditions and climate change impacts.

19.3. Emergent Risk: Multiple Interacting Systems and Stresses

19.3.1. Limitations of Previous Approaches Imply Key Risks Overlooked

Interactions between climate change impacts in various sectors and regions, and between these impacts and human adaptation in other sectors and regions, as well as interactions between adaptation and mitigation actions, are generally not included, or not well integrated, into projections of climate change impacts (Warren 2011). These interactions create emergent risks and/or key vulnerabilities not previously recognized. There are a very large number of potential interactions, and many important ones have not yet been quantified, meaning that some key risks have been overlooked. In some cases, new knowledge about these risks is just now emerging. The six interaction processes listed below, while not exclusive, are systemic and are *likely* to lead to further key vulnerabilities as well as a larger number of less significant impacts. Several of these are discussed in more detail in the following sections.

- Climate change induced biodiversity loss erodes ecosystem services, in turn affecting human systems dependent on those services. (*19.3.2.1)*
- Climate change induced changes in extreme weather events affect human systems and ecosystems, which preconditions these systems and increases vulnerability to the effects of mean climate change. Most impacts projections are based only on changes in mean climate (Rosenzweig & Hillel 2008).
- Interactions with non-climate stressors: the interaction between climate change impacts and population/economic growth is well studied, but a large literature now addresses interactions of climate change with other factors such as land management, water management, air pollution (which has drivers in common with climate change) and energy production (*19.3.2.2)*
- Interactions related to climate change and disease emergence *(19.3.2.3)*
- Co-location of impacts in different sectors can create impact 'hotspots' involving new interactions (*19.3.2.4)*
- Adaptation designed for one sector interacts with functioning of another sector (e.g. increasing irrigation to crops in response to a drying climate can exacerbate water stress in downstream areas such as wetlands, in cases where the latter provide important water cleaning services). (*19.3.2.5)*

19.3.2. Emergent Risks

19.3.2.1. Emergent Risks Arising from the Effects of Degradation of Ecosystem Services by Climate Change

The large proportion of the world's species that are projected to become at risk of extinction from mean climate change [CITE Ch 3], which includes a large proportion of the world's widespread species (Warren et al submitted), together with the projected effects of climate-change induced increases in extreme events such as drought and increased forest losses due to fire; and the resulting potential for disruption of mutualistic or predator-prey relationships between species, translates into an emergent risk from a large scale loss of ecosystem services in both terrestrial and marine systems (Mooney et al 2009). Biodiversity loss is linked to disruption of ecosystem structure, function and services (Gaston et al 2008, Maestre et al. 2012, Diaz et al 2006, Midgley 2012).

Examples of at-risk services include water purification provided by wetlands, air purification by forests, crop pollination by insects, coastal protection from storm surge by mangroves and coral reefs, regulation of pests and disease, recycling of waste nutrients, and removal of carbon from the atmosphere (Chivian & Bernstein, 2008). Biodiversity loss has now been linked to increased transmission of infectious diseases such as Lyme, Schistosoma and hantavirus in humans, and West Nile virus in birds (Keesing et al. 2010).

The following studies provide examples of projected ecosystem service loss in the agricultural sector due to climate change: projected crop damage due to increased prevalence of pest species including *Fusarium graminearum* (a fungal disease of wheat), the European corn borer, the Colorado beetle, bakanae disease and leaf blights of rice (Petzoldt et al. 2006, Chakraborty & Newton, 2011, Magan et al 2011, Kocmankova et al. 2010, Huang et al 2010); and projected declines in crop yields due to climate change effects on pollinating species (Hillel & Rosenzweig 2008, others). These effects are simultaneous with climate change's direct effects on yields through changing temperature, precipitation, and ambient carbon dioxide concentrations. Climate change has caused, or is projected to cause range expansion in a number of weeds that have the potential to become invasive (Clements & Ditommaso, 2011; Bradley et al 2009a). Invasive species can damage agriculture and cause extinction of other species, with attempts to control them being extremely costly (eg $120 billion annually in the USA, Crowl et al 2008). Whilst the balance of gains and losses for invasive species will vary locally (Bradley et al 2009b) and no single aspect stands out, any one of the mechanisms mentioned in this paragraph has the potential to cause outcomes that are very damaging and act in synergy with existing climate change impacts on agriculture. Hence, these various susceptibilities to loss of ecosystem services taken together comprise a key vulnerability, and in interaction with climate change, an emergent risk.

Estimates of the current value of the ecosystem services of pollinators in the UK are UK430 million per year yet the study also noted that this service is currently becoming less effective (UKNEA 2011). The same study found that the recent increase in woodland from 6 to 12% of the UK's land area (with the reverse being a measure of the cost of degradation) was worth £680 million per year in carbon sequestration value alone. Ecological function analysis for Chinese terrestrial ecosystems yielded estimated economic values of approximately 0.3-1.6 x 10^{13} yuan annually for services such as CO2 fixation, O2 release, nutrient recycling, soil protection, water holding capacity and environmental purification (Ouyang et al 2006). Similarly, the value of ecosystem services in US forests has been estimated at values ranging from 1 to 6 billion annually for climate regulation, 4-54 billion for biodiversity, and 1 to 100 billion annually for recreation (Kriegler 2001). The potential loss of coral reefs (section *19.3.2.4*) would result in a loss of income of $Au4 billion to the Australian economy from international tourism, of US$1.6 billion to the Caribbean economies for tourism and fishing on reefs, and the loss almost equal to the value of the entire economy of the Maldives and the Seychelles (Hoegh Guldberg 2011). Such costs are represented only very crudely, if at all, in aggregate global models of the economic impacts of climate change where 'non-market impacts' are estimated very broadly if at all (section 19.6.3.4).

Some of the work on degraded ecosystems and their interaction with economic sectors examines the cost of restoring ecosystem services. For example, interviewed households along the Platte River (US) showed a willingness to pay, in terms of increased water bills, an additional US$20 per month in order to improve five ecosystem services (Loomis et al, 2000), while the total amount "paid" is US$19 to US$70 million dollars which greatly exceeds the estimated costs of improving degraded ecosystem services (US$1.13 to US$12.3 million). A meta-analysis of 89 studies looking at the restoration of ecosystem services found that restoration increased the amount of biodiversity and ecosystem services by 44 and 25%. However, even after restoration, the values in restored ecosystems were lower than in intact ecosystems (Rey Benayas et al 2009).

Concomitant stress from land use change increases the likelihood that climate change impacts on biodiversity would result in increased extinction rates, since larger areas of contiguous habitat support relatively greater numbers of species by reducing edge effects. In addition, if species attempt to adapt to climate change by moving, fragmentation can create impassable barriers between an area of suitable habitat that is no longer climatically favorable and one that is newly favorable (in prep, Berry et al UK scale study). Land clearing not only releases carbon to the atmosphere but removes carbon sinks (Warren et al in prep., X-ref WG1), in part because old growth forests continue to accumulate carbon (Lussayert 200x). A new approach has quantified the 'Greenhouse Gas Value' of ecosystems (Anderson-Teixera and Delucia 2011), taking into account both fluxes and storage of carbon, implying that published values of ecosystem services from carbon sequestration have tended to underestimate their importance due to a tendency to consider only the carbon currently stored in the systems.

19.3.2.2. Emergent Risk Involving Non-Climate Stressors: the Management of Water, Land, and Energy

19.3.2.2.1. Interactions among water use, energy, adaptation, and mitigation, and agriculture

One of the most important interactions affecting the well-being of humans and ecosystems and the level and rate of climate change, are those involving human management of water, land, and energy. These profoundly affect the amount of carbon which can be stored in terrestrial ecosystems, the amount of water available for use by humans and ecosystems, and the viability of adaptation plans for cities or protected areas, for example. Failure to manage land, water and energy in a manner which maximizes synergy among management strategies can itself greatly increase the vulnerability of local populations and/or ecosystems, and can exacerbate climate change impacts globally.

The projected increase in climate variability combined with water extraction leads to an emergent risk: that of water stress exacerbated by the removal of groundwater which serves as 'an historical buffer against climate variability' (Green et al 2011). The use of energy by the water sector, including domestic use for heating, accounts for between 5-6% of the greenhouse gas emissions of the US and India. Extraction and conveyance of water for irrigation is energy intensive and this demand is projected to rise as adaptation to climate change and increasing food demand drives the need for an expansion of irrigated cropland. This has implications for projected energy use and hence mitigation strategies.

However, there are opportunities for adapting the agricultural sector to climate change in drying regions which reduce greenhouse gas emissions, such as advanced irrigation systems (Rothausen & Conway, 2011). The second issue is that of groundwater extraction, which is *likely* to increase as an adaptation to climate change, since current demand for surface water will not be met under various scenarios of a changed climate (Barnett et al, 2008). For example, following a ten-fold increase in groundwater extraction in China, 70% of the irrigated cropland in China is now groundwater fed, and it is estimated that 0.5% of the country's greenhouse gas emissions are attributable to exploitation of this resource (Wang et al 2012). The effects of climate change on groundwater are varied with some areas expecting decreases recharge, whilst others are projected to experience increased recharge (Green et al 2011). However, in areas where extraction rates increase or recharge decreases, water tables will be depleted with consequence for ecosystems and the human systems (such as agriculture, tourism and recreation) which depend upon them, while water quality will also decrease. One projection shows insufficient water availability in Africa, Latin America and the Caribbean to satisfy both agricultural demands and environmental regulations by 2050, owing to increases in demand for water use for municipal and industrial use, combined with increases in demand for food, a situation that is exacerbated by climate change (Strzepek & Boehlert 2010).

19.3.2.2.2. Interactions among biofuel development, land use management, and agriculture

Primary biofuel production, when not carefully managed, often displaces use of land for food cropping or natural, unmanaged ecosystems. Reductions of greenhouse gas emissions from biofuel production and use (compared to fossil fuels) may be offset partly or entirely for decades or centuries by emissions from the resulting indirect land-use changes (iLUC) (IPCC SRREN 2012) some of which are not only indirect but have transboundary and/or distant impacts (see 19.4). Particular types of biofuel production, especially second generation biofuels, can reduce GHG emissions and other air pollutants compared to fossil fuel use (Fargione 2010; Plevin 2009).

There can be important interactions between global mitigation policies and land management which can either confound, or contribute to, mitigation by affecting the above tradeoffs. In particular, the placement of a carbon tax (as a surrogate for the effect of a variety of policies) to fossil carbon only, with a goal of limiting CO2 concentrations to 450ppm-550ppm, is projected to lead to large scale deforestation of all natural forests, with conversion of most other natural ecosystems, in part due to enhanced biofuel production (Wise et al 2009, Mellilo et al 2009a,b). If instead the tax is applied also to include terrestrial carbon, the area of forested land *increase*s. Dietary changes could reduce the land requirements of food cropping embodied in these tradeoffs. Specifically, a transition to a vegetarian diet would free up 2700 Mha of pasture and 100 Mha of cropland, 75% of which could be used for biofuel cropping (Stehfest et al 2009), whilst the remainder could revert to natural vegetation becoming a carbon sink (see 19.3.2.1).

More generally, should mitigation be achieved with a substantial contribution from biofuel cropping, a number of emergent risks apply, as shown in the Table 19-1.

[INSERT TABLE 19-1 HERE
Table 19-1: Emergent risks related to biofuel production as a mitigation strategy.]

Strategies exist that can reduce some of the above interaction problems, in particular iLUC. Whilst the iLUC itself associated with a particular biofuel project can be difficult to measure (because accounting can be complex and assumption dependent, as in the case of in Brazil’s ethanol industry (Lapola et al 2010; Barr 2011), iLUC reduction strategies can be adopted. These include ensuring that increases in land use due to biofuel production is accompanied by concomitant improvements in agricultural management, such as intensification (Stehfest et al 2011, IPCC SRREN 2012); establishing bioenergy plantations on marginal and degraded soils where CO2 might potentially thus be sequestered; and appropriate land use governance (zoning) (IPCC SRREN 2012, Fargione et al 2010). More generally the rate of improvement of agricultural and livestock management, including fertiliser management, is key to the avoidance of iLUC issues; but the issue of enhanced emissions of N2O still remains.

19.3.2.3. Emergent Risks Involving Health Effects and Disease Emergence

Climate change will act through numerous direct and indirect pathways to alter the prevalence and distribution of diseases that are climate and weather sensitive. These effects will differ substantially depending on current epidemiologic profiles, reflecting the level of development and access to clean and plentiful water, food and access to health care resources. Furthermore, the impact of climate change will differ by region, depending upon the adaptive capacity of critical public health infrastructure that ensures access to clean food and water.

A principal emerging global risk is malnutrition secondary to ecological changes and disruptions in food production as a result of changing rainfall patterns, increases in extreme temperatures and precipitation events (SREX), and increased atmospheric CO2 (Burke and Lobell 2010, Taub 2008). Modeling of the magnitude of the effect of climate change on future under-nutrition in five regions in South Asia and sub-Saharan Africa in 2050 suggests an increase in moderate nutritional stunting of 1% to 29% compared to a future without climate change, and a much greater impact on severe stunting of 23% for central sub-Saharan Africa and 62% for south Asia (Lloyd et al 2011). The impact of climate induced drought and precipitation changes in Mali inlcude the southward movement of drought-prone areas which would result in a loss of critical agriculturally-productive land by 2025 and increase food insecurity (Jankowska et al 2011).

In developed countries and large, highly populated megacities with developed public health infrastructure, principal risks include increased injuries and fatalities as a result of severe storms and heat waves; changes in vector biology and disease ecology that impact infectious diseases; water and food contamination; increased pollen production leading to increases in allergic airway diseases (see 19.5.3); and respiratory and cardiovascular morbidity and mortality secondary to degraded air quality and ozone formation. Indirect effects, for which data and evidence to support projections are less available and uncertainties are greater, include mental health consequences resulting from population dislocation, and nutritional shortages related to changes in food production (Portier et al 2010).

Increase in heat-related morbidity and mortality subsequent to the increase in the severity, duration, and frequency of heat waves (Luber and McGeehin 2008) in urban areas is an emergent risk. These impacts will be greatest in urban areas with a pronounced urban heat island effect (Kovats and Hajat 2008). The coupling of the increasing vulnerability of an aging population and a global shift to urbanization will increase the likelihood of relatively higher mortality from exposure to excessive heat (Knowlton et al., 2007). In addition to heat waves, climate change is projected to alter the frequency, timing, intensity, and/or duration of extreme weather events, such as tropical cyclones, heavy precipitation events, and floods (see WGI AR5 Ch x, SREX). The health effects of these extreme weather events range from the direct effects, such as loss of life and acute trauma, and mortality resulting from the exacerbation of chronic disease, to indirect effects, including large-scale population displacement, damage to water and sanitation infrastructure, damage to the health care infrastructure, and psychological problems such as post-traumatic stress disorder (Frumkin et al 2008).

While the association between ambient air quality and health is well established, there is an increasingly robust body of evidence linking spikes in respiratory diseases to weather events and to climate change, so that this interaction is emerging as a key risk. In New York City, for example, each single degree (Celsius) increase in surface temperature has been associated with a 3% increase in same-day hospitalizations due to respiratory diseases, and an increase of up to 3.6% in hospitalizations due to cardiovascular diseases (Shao Lin 2009). The principal pathways through which such respiratory health outcomes will be exacerbated by climate change are through increased production and exposure to tropospheric (ground-level) ozone, smoke produced by wildfires, and increased production of pollen (D'Amato 2010). Many of the same populations that are vulnerable to health effects from heat waves, show increased risk for effects from poor air quality induced by heat, including: the very young and the very old and those with preexisting medical conditions, including respiratory and cardiovascular disease.

Projected changes in precipitation, temperature, humidity, and water salinity, would affect the distribution and prevalence of food- and water-borne diseases resulting from bacteria, overloaded drinking water systems, and increases in the frequency and range of harmful algal blooms (Curriero et al., 2001, Moore et al 2008). Climate change and increased climatic variability are particularly would affect vector-borne diseases such as plague, Lyme's disease, malaria, hanta virus, and dengue fever which exhibit distinct seasonal patterns and sensitivity to ecologic changes (Githeko et al 2000, Gage 2008, Parham et al. 2011 submitted).

19.3.2.4. Spatial Convergence of Multiple Impacts: Hotspots

In this chapter, hotspot is defined as a region where climate-change induced impacts in one sector affects other sectors in the same region or a region where climate change impacts in different sectors are compounded, resulting in extreme or disastrous consequences. The coincidence of impacts in different sectors in the same region could have consequences that are more serious than simple summation of the sectoral impacts would suggest. Such synergistic processes are difficult to identify through sectoral assessment and apt to be overlooked in spite of their potential importance in considering key vulnerabilities. For example, a large flood in a rural area may damage crop fields severely, causing food shortages (Stover and Vinck, 2008). The flood may simultaneously cause a deterioration of hygiene in the region and the spread of water borne diseases (Hashizume et al., 2008; Schnitzler et al., 2007; Kovats and Akhtar, 2008). The coincidence of disease and malnutrition can thus create a hotspot for health impacts, with the elderly and children most at risk.

Identification of hotspots could be achieved by overlaying spatial data on impacts in multiple sectors, but this cannot indicate synergistic influences and dynamic changes in these influences quantitatively. For global analysis, certain types of integrated assessment models which allow spatial analysis of climate change impacts have been used to identify regions that are affected disproportionately by climate change (Fussel, 2010; Tol and Fankhauser, 2008, Kainuma et al., 2003; Bowman et al., 2006; Warren et al., 2008). Recent efforts attempt to collect and archive spatial data on impact projections and facilitate their public use. These have created overlays for identifying hotspots with web-GIS technology (Adaptation Atlas (Vajjhala, 2009). There are also efforts to coordinate impacts assessments based on shared future scenarios at various spatial scales (Parry 2004; ISI-MIP, 2012).

[TO BE INSERTED HERE: examples of coordinated regional/national/city assessment of climate change impacts and suggested hot spots from regional chapters]

Below are some examples of hotspots where climate change impacts coincide and interact:

1) The Arctic, where the Inuit culture (Crowley et al 2011) is projected to be exposed to the disruption, and possible destruction of, their hunting and food sharing culture. This hotspot is due to the combination of sea ice loss and the concomitant potential extinction of the animals dependent upon the ice (Johannessen et al 2011). Thawing ground is also disrupting transportation, buildings and infrastructure whilst there is increased exposure to storms. Alaskan ecosystems are considered particularly at risk (Kittel et al 2011)
2) Coral reefs, which are highly threatened due to exposure to concomitant sea surface temperature rise and ocean acidification. (Hoegh Guldberg, 2011) considers that reefs could not persist should CO_2 concentrations reach 450ppm by 2100, as this would reduce the carbonate concentration of the ocean to below a critical level of 200umol/kg, and given the climate sensitivity used, increase sea surface temperatures by at least 2C. A ‘safe’ level of 324 ppm has been suggested (Royal Society 2009).
3) Placeholder: a South Asian coastal city where citizens are projected to be at risk of a combination of coastal flooding, heat-related deaths, etc. Cities in deltas are impact hotspots: An assessment of combined impacts of sea level rise, increased storm surge and natural and anthropogenic subsidence in deltas under a moderate scenario for sea level rise (Ericson et al 2006, AR4 WGII) revealed that over 6 million people would be at risk of enhanced inundation and increased coastal erosion in three megadeltas and 8.7 million in 40 deltas, absent measures to adapt.
4) Placeholder: a similar city in Africa, including food insecurity

General equilibrium economic models (see chapter 10) may facilitate quantitative evaluation of synergistic influences. An analysis of the EU by the PESETA project evaluated sub-regional welfare loss by considering impacts on agriculture, coastal system, river floods, and tourism together in the CGE (Computable General Equilibrium) model, which is designed to represent interrelationships among economic activities of sectors, and indicated the largest percentage loss in Southern Europe (Ciscar et al., 2011). It should be noted, at any scale, choices of sectors are strongly constrained by availability of data or evaluation methods and they are not comprehensive.

19.3.2.5. Maladaptation

Maladaptation refers to adaptation strategies that increase a population or sector’s vulnerability to climate change. The IPCC Third Assessment Report defines maladaptation as “an adaptation that does not succeed in reducing vulnerability but increases it instead” (IPCC 2001, 990). More recent treatments of this concept refine this definition to an “action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups” (Barnett and O’Neill 2010, 213). More generally, maladaptation occurs “where the human response actively undermines the capacity of society to cope with climate change or further contributes to the problem” (Niemeyer et al. 2005, 1443). Maladaptations can take numerous forms, but quite commonly the maladaptation results from a narrowly focused approach that attempts to reduce impacts in one sector or region without considering the consequences for others. Maladaptation can operate on different temporal and spatial scales, including, for example, adaptation actions or policies that increase greenhouse gas emissions, those that disproportionately burden the most vulnerable, have high opportunity costs, reduce individual incentives to adapt, and set paths that limit the choices available to future generations. An assessment of potential adaptation actions in the context of interactions across multiple sectors and regions would identify potential negative impacts (Barnett and O’Neill 2010, 212). Lack of consideration of such interactions is itself an emergent risk, in that it could cause new risks to emerge (see 19.6.x on governance).

Most clearly identified as in this category are those adaptation actions in one sector that impact another sector within the same region (Warren 2011, 218). Increasing irrigation in agriculture uses water which may be required to maintain a healthy wetland; and the building of dykes to protect towns can be to the detriment of associated natural ecosystems (Knogge et al 2004, xxxx et al. 2008) or adjacent settlements (Ericson et al. 2006); in addition to its benefits for crop productivity locally, agricultural intensification (World Bank, 2011) entrains negative impacts such as reduced biodiversity. Water stress in Burkina Faso, Sudan and Egypt has encouraged dam construction to ensure water resource resiliency. Dam building has led to has damaged wetlands and stimulated the reproduction of parasites in lakes nearby human settlements, leading to schistosomiasis and malaria (Molyneux et al. 2008). In theory, process-based impact models represent one way to quantify these interactions, but only a few interactions have presently been simulated within models (Warren 2011, 235). Another way to assess maladaptative responses is to qualitatively examine social responses. For example, the incentive for individuals to cooperate may decrease if they perceive that public institutions are unwilling, or unable to increase their adaptive response (see 19.6.x on governance). One method to examine how human responses to climate change may influence subsequent behavior is to analyze people's perceptions of various climate change scenarios in order to understand what drives their behavior (Niemeyer et al. 2005, 1444).

19.4. Emergent Risk: Indirect, Trans-Boundary, and Long-Distance Impacts

Climate change impacts can have consequences beyond the regions in which they occur. Such long distance interactions may be mediated by global trade systems. The most prominent example of this is the global food trade system. Similarly, both mitigation and other adaptation responses that are implemented on the ground can have unintended consequences beyond the locations in which they are implemented. All of these mechanisms can create emergent risks.

19.4.1. Indirect, Trans-Boundary, and Long-Distance Impacts of Climate Change Impacts on Agricultural Yields: Food Trade Patterns, Prices, Malnutrition

Climate change impacts on agriculture can have consequences beyond the regions in which those impacts are directly felt, through the global food trade system. Food access can be inhibited by rising food prices, as demonstrated during recent price rise episodes that resulted from the combination of poor weather in certain world regions combined with a demand for biofuel feedstocks , increased demand for grain-fed beef in China, and historically low levels of food stocks (Abbot & deBattisti 2011, Adam & Ajakaiye 2012). This episode provides an analog elucidating how reduced crop yields due to climate change impacts and biofuel cropping create a risk of malnutrition: hence this interaction of climate change with the food system via markets comprises an emergent risk of the impacts of climate change acting a distance.

One study finds that climate change has already significantly offset technology-related increases in crop yields in the last 30 years in several countries including Russia, Turkey and Mexico (wheat) and China (maize) (Lobell et al 2011) while another identified areas where past climate variability has induced sudden or prolonged drops in food production, e.g., Ukraine (a 13% decline in a single year due to high summer temperatures) and the Sahel (decadal scale losses due to prolonged drought and high temperatures) (Battisti & Naylor, 2009). In the next few decades, areas where crop yields are projected to decline such as sub-Saharan Africa and the Sahel may come to rely more strongly on imported food (Scmidhuber & Tubiello, 2007). Whilst some studies (Jaggard et al. 2010, other refs) conclude that in the next few decades, there may be increases in crop yields in temperate regions which may compensate in global terms for the losses in tropical regions (FAO, 2008), a recent empirical study suggests that these benefits may not be realized, based on indications that, to date, the positive effects of CO_2 fertilisation on yields and the effects of changes in precipitation and temperature have offset one another (Lobell & Field, 2007). Median projected temperatures from AR4 are higher than any year on record in most tropical areas by 2050. Taken together, the evidence points to an increased risk (compared to the assessment in AR4) that significant crop yield declines will occur in tropical and sub-tropical regions.

Regional climate change impacts on crop yields would result in increased prices of food commodities on the global market (Lobell et al. 2011, Battisti & Naylor 2009) even under an assumption of barrier-free ability to change the areas under cultivation (Julia and Duchin 2007). Weather-induced yield losses, such as drought in Australia and Europe which occurred in recent years have affected food prices in many countries (World Bank 2011, FAO 2008), for example increasing the number of malnourished people by 75 million in 2007 [CITE]. While many of these price rises may not be related to climate change, climate change is projected to increase the frequency of extreme weather that can reduce in crop yields and increase their year-to-year variability (Diffenbaugh et al 2012; Urban et al 2012), and there is some specific evidence that climate change induced yield losses are already affecting food prices (Lobell et al. 2011). Furthermore, developing countries which have limited financial capacity for trade, and/or food distribution networks may be damaged by increases in extreme weather events (FAO 2008) leading to increased risk of poverty and malnutrition. One study used historical vulnerability to extreme weather events to project that Bangladesh, Mexico, Mozambique, Malawi, Tanzania and Zambia would be most at risk under 21st century climate change in the SRES A2 scenario (Ahmed et al 2009), whilst another (Jones & Sanyang 2008) noted that experienced food price rises have reduced food security in African countries, especially in Kenya and Ethiopia. Developed countries which currently enjoy imported foods from tropical regions that become affected by climate change, would see the prices of those commodities rise. More generally, pressure on land use for biofuels is *likely* to further exacerbate food prices (see sections 19.3.2.2.2, 19.4.2.1).

On longer timescales, new techniques for assessing climate change impacts on yields of soybean, maize and cotton (Schlenker & Roberts 2009) result in higher projections of yield declines compared to studies assessed in AR4: yield losses reach 30-46% by the end of the century under a low emissions scenario, or 63-82% under a high emissions scenario. However, these approaches are not necessarily accepted as better than earlier studies (Xref Ch 7). Global rice prices may be particularly sensitive to climate change (Chen et al 2012), potentially rising by 7-13% in the wake of projected 1.6-2.7% losses in yield resulting from a combination of climate change and sea level rise. Another study (Warren et al 2011) highlights that 50% of the world's cropland is projected to become less suitable for cultivation over the same period. A recent report (Foresight, 2011) highlights the combined agricultural land losses expected in the next 40 years, due to desertification, erosion and sea level rise (the latter leading to increased salination). The report does not estimate the percentage of agricultural land involved, but if large, such changes would further increase global food prices, increasing the risk of poverty and malnutrition (World Bank, 2011).

19.4.2. Indirect, Trans-boundary, and Long-Distance Impacts of Adaptation

Risk can also emerge from unintended consequences of adaptation (see 19.3.2.5), and this can act across distance, if for example, there is migration of peoples or species from one region to another. Adaptation responses in human systems can include land use change which can have both trans-boundary and long distance effects; and changes in water management, which often has downstream consequences. In some cases such interactions may contribute to conflict.

19.4.2.1. Human Migration and Displacement

Human migration is one of many possible adaptive strategies or responses to climate change (Reuveny 2007; Piguet 2008; Tacoli 2009: McLeman 2011). Regional climatic changes are among the many factors which have contributed to migration to urban areas as individuals seek work for the purpose of sending remittances home. By pursuing economic opportunities in other regions, people build resilience to climate impacts by distributing risks of economic loss through income diversification and circular mobility patterns (Adger et al. 2002; Tacoli 2009). Displacement refers to situations where choices are limited and movement more or less compelled by land loss due to sea level rise or extreme drought, for example (see AR5 WGII chapter12.4). A number of studies have linked past climate variability to both local and long distance migration (Lilleør and Van den Broeck 2011). In addition to positive and negative outcomes for the migrants, migration from one region results in significant indirect, (and in some cases, long distance) effects on people and states in other regions. Consequences for receiving regions, determined by a variety of metrics, could be both positive and negative, as may also be the case for sending regions (McLeman 2011; Foresight 2011; AR5 WGII Chapter 12). An emerging literature examines potential changes in migration due future climate changes but projections of specific positive or negative outcomes are not yet available. Nevertheless, the potential for negative outcomes is an emergent risk of climate change. Furthermore, recent literature underscores risks previously ignored: risk arising from the lack of mobility in face of a changing climate, and risks entailed by those migrating into areas of enhanced risk, like low-lying coastal deltas (Foresight 2011; see Chapter 12).

Past experience suggests that population movement within vulnerable countries would be the predominant mode of migration in response to climatic and other environmental stress (McLeman 2011; Massey et al 2010; de Haas 2011) with, however important exceptions (Feng et al 2010, Marchioli et al 2012) where international migration could be large. In areas with strong economies, rural-urban migration is currently predominant. It is, however, not the only form of movement that can occur inside countries. Rural-rural migration is particularly widespread in agriculture-based economies (Tacoli 2009). In Burkina Faso, temporary moves to other rural areas have increased as a result of a reduction in rainfall (Henry et al. 2004), indicative of a sensitivity also seen in agent based modeling of future responses (Kniveton 2011). Furthermore, the local and regional nature of past climate variability limits its utility as an analog for the effect of future global scale climate changes on migration. Climate change-induced drought has prompted both short-distance (Tacoli 2009) and long distance international migration, with the Mexican drought of the 1990s providing an example of the latter (Saldaña-Zorrilla S, Sandberg K 2009; Feng et al 2010).

Several studies have discussed potential future migration resulting from climate change on a global or regional basis (Myers 2002; McLeman and Smit 2006; Stern 2007; Warner 2009), including some global estimates of very large flows (Myers and Kent 1994). Three recent studies use statistical analysis to isolate and quantify migration responses to past climate variability and then project migration later in this century assuming sensitivity to future climate changes resembles that to past variability. These studies attempt to distinguish past climate-driven migration from the influences of variations in non-climate factors that may simultaneously affect migration behavior, such as policies affecting domestic and international migration as well as unrelated political, economic and household factors. A study of Mexico-US immigration under the B2 warming scenario projects cumulative immigration by late in this century of 1.4-6.4 million additional people due to the effects of climate change on the agricultural sector alone (Feng et al 2010). A similar approach to US domestic migration projects that 3.7% of the adult population (ages 15-59) will emigrate from rural counties of the Corn Belt in the medium term (2020-2049) under the B2 scenario (Feng et al 2011). A study examining the relationships among climate variability, wages, and urbanization (Marchiori et al 2012) projects that under A1B and mid-range regional population growth, an additional 11.8 million people will migrate annually from and within Sub-Sahara Africa. To different extents, all three studies are ceteris paribus and thus unable to account for shifts in national demographic (Hugo 2011) and income structures, and pre-existing immigrant networks (Munshi 2003), which interact with the influence of climate and which pose a significant challenge (Hunter 2005) to any analysis aimed at singling out the effects of climate change. In addition, omitted variable bias may limited the value of the projections in the Marchiori et al (2012) study (Lilleør and Van den Broeck 2011). Nevertheless, all three studies find a sensitivity of migration to past climate variations and support the general conclusion that future climate change of similar or greater magnitude will affect migration flows in a significant way.

A study using a different approach, modeling the effect of changes in land value on incomes in the agricultural sector, projects substantial climate-driven migration of approximately 20,000 (SRES B2) to 250,000 (SRES A2) for the period 2045-2050 in Northeast Brazil (Barbieri et al 2010). This method has the disadvantage of not drawing on the past climate-migration relationship but has the advantage of avoiding some of the limitations of a ceteris paribus approach. The potential international component of migration was not estimated.

Taken together, these studies indicate that substantial numbers of people may migrate under the influence of climate change, creating risks as well as benefits for themselves and for sending and receiving regions and states. While a literature projecting climate-driven migration has emerged, there is as yet insufficient literature which projects region-specific consequences of such migration.

Climate change induced sea level rise, in conjunction with storm surges and flooding, creates a threat of temporary and eventually permanent displacement from low-lying coastal areas, the later particularly the case for small island states (Pelling and Uitto 2001). The extent to which these responses are employed will depend on whether governments develop strategies such as relocating people from highly vulnerable to less vulnerable areas nearby and conserving ecosystem services which provide storm surge protection (Perch-Nielsen 2004) in addition to so-called "hardening" such as building sea walls and storm barriers (Nordenson and Seavitt 2011). Numbers of people at risk from coastal land loss have been estimated (Nicholls and Tol 2006, Ericson 2006, Nicholls et al 2011) but projections of resulting anticipatory migration or episodic and permanent displacement are not available.

19.4.2.2. Conflict and Insecurity

Violent conflict between individuals or groups arises for a variety of reasons; for example, violence may be used to intimidate political or economic competitors, to redistribute or protect property rights, or to permanently alter social institutions. When individuals or groups employ violence to achieve these or other objectives, they do so because it dominates alternative actions (Fearon and Laitin, 2003, Collier and Hoeffler, 2007, Chassang and Padro-i-Miquel, 2009, Blattman and Miguel, 2010, Besley and Perssen, 2011, Dal Bo and Dal Bo, 2011). It has been hypothesized that climatic changes can alter the prevalence or nature of violent conflicts by altering the environment in which agents decide whether or not to take violent actions (Homer-Dixon, 1991, Diamond, 2005, Barnett and Adger, 2007). Violent conflict may become more prevalent if climate change increases the value of capturing control rights to current or future resources (Dube and Vargas, 2007, Angrist and Kugler, 2008, Lei and Michaels, 2011), reduces the benefit of peaceful employment (Miguel et al., 2004, Dube and Vargas, 2007, Schlenker and Roberts, 2009, Hidalgo et al. 2010, Hsiang, 2010, Barrios et al., 2010, Jones and Olken, 2010, Dell et al, forthcoming), weakens the institutions or governments that enforce the status quo (Burke and Leigh, 2010, Zhang et al., 2011, Bruckner and Ciccone, 2011, Chaney, 2011, Burke, 2011), increases socio-economic inequality (Davis, 2002, Grove 2007, Hidalgo et al. 2010, Zhang et al., 2011, Anttila-Hughes and Hsiang, 2012), makes the execution of violent activities logistically easier (Meier et al. 2007, Harari and Ferrara, 2011, Butler and Gates, 2012), or directly alters the decision-making process of individuals at the cognitive-psychological level (Kenrick and Macfarlane, 1986, Anderson et al., 2000, Jacob et al., 2007, Larrick et al., 2011).

A large number of empirical studies have implicated climatic events as a contributing causal factor to the onset or intensification of violent conflicts and social instability around the world, across a variety of spatial and temporal scales [See Section 18.4.5.1] with most studies released after AR4 (Kenrick and Macfarlane, 1986, Anderson et al., 2000, Cullen et al., 2000, DeMenocal, 2001, Haug et al., 2003, Miguel et al., 2004, Levy et al., 2005, Kuper and Kropelin, 2006, Zhang et al., 2006, Hendrix and Glaser, 2007, Jacob et al., 2007, Zhang et al., 2007, Grove 2007, Yancheva et al., 2007, Burke et al., 2009, Bai and Kung, 2010, Tol and Wagner, 2010, Hidalgo et al. 2010, Buckley et al., 2010, Bohlken and Sergenti, 2010, Pasquale and Travaglianti, 2010, Bruckner and Ciccone, 2011, Couttenier and Soubeyran, 2011, Hsiang et al., 2011, Harari and Ferrara, 2011, Chaney, 2011, Zhang et al., 2011, Burke, 2011, Larrick et al., 2011, Hendrix and Salehyan, 2012, Theisen, 2012). It remains unclear whether climatic events contribute to the likelihood of violence through one of the pathways above or some other mechanism (Sutton et al., 2010, Hsiang & Burke, 2012, Gleditsch, 2012, Bernauer et al. 2012), however the large number of new studies finding such an association indicates that changing patterns of violence should be considered an emerging risk.

The strongest studies of modern data examine whether high-frequency variations of climatic variables are associated with rapid changes in the risk of violence (Hsiang & Burke, 2012). In these studies, the range of annual variations of temperature, precipitation or water availability observed since midcentury is generally associated with changes in the risk of various types of conflict by a factor of two (Hsiang & Burke, 2012). Because annual variability is expected to increase for many locations under warming scenarios, these findings are directly relevant to the projection of future social impacts. Furthermore, since future changes in mean climate conditions may be large in magnitude compared to historically observed annual variability, extrapolating these historical associations to future warming scenarios suggest that conflict risks might increase dramatically (Burke et al., 2009).

It has been suggested that gradual changes in locations' mean climates should not exacerbate violence as much as historical variability because populations may successfully adjust to slowly changing conditions in non-violent ways (Buhaug, 2010, Hsiang et al. 2011, Gleditsch, 2012); however, it is also argued that since gradual changes are more persistent, they may be more challenging to cope with because the conflict-buffering capacities of exposed populations are replenished less often (Haug et al., 2003, Hendrix and Glaser, 2007, Buckley et al., 2010, Couttenier and Soubeyran, 2011, Bruckner and Ciccone, 2011). In order to observe populations exposed to gradual but persistent climate changes that are decades, centuries or longer in duration, empirical researchers examine historical records, archeological remains and paleo-climatic data that necessarily predate the twentieth century (Stahle et al., 1998, Cullen et al., 2000, DeMenocal, 2001, Haug et al., 2003, Kuper and Kropelin, 2006, Zhang et al., 2006, Zhang et al., 2007, Yancheva et al., 2007, Buckley et al., 2010, Tol and Wagner, 2010, Bai and Kung, 2010, Stahle, 2010, Chaney, 2011, Zhang et al., 2011). While these older data describe historical climate changes that are a better proxy for anthropogenic warming than annual climate variations, the societies exposed to these changes are substantially weaker proxies for modern societies (Hsiang & Burke, 2012).

A weakness with all studies making inferences from past behavior is the extent of ceteris paribus assumptions made, in the same way that such assumptions place limitations on migration projection studies (see 19.4.2.1). Bearing this caveat in mind and recognizing the limited value of negative inferences, it is nevertheless notable that in the historical conflict studies above, there are many examples where gradual and persistent changes were associated with higher rates of violence and less stable social, political or economic conditions, and there is little evidence that gradual and persistent climate changes did not affect the likelihood of violent conflict.

19.4.2.3. Species Range Shifts: Consequences

One of the main adaptations of species to climate extremes and climate change is to move to more climatically suitable areas. The resulting losses, gains, and changes in species abundance are having, and will continue to have, profound impacts on how ecosystem function, posing risks to the services they provide (Dossena et al., 2012; Millennium Ecosystem Assessment, 2005), including those related to climate regulation (Wardle et al. 2011). For example, warming-driven expansion and intensification of Mountain Pine Beetle outbreaks in North American pine forests have caused both declines in timber harvest and the conversion of forests from net carbon sinks to large net carbon sources (Kurz et al., 2008). Predicted negative impacts of range shifts include redistribution of important resource species (e.g. marine fishes, where catch potential is predicted to increase by 30-70% in high latitude regions and decline by 40% in the tropics by 2055 (Cheung et al. 2010)), as well as new introductions of diseases to people, livestock, crops and native species (Chakraborty & Newton, 2011; Jepsen et al., 2008; Gale et al., 2009; Lafferty, 2009). Newly arrived species may prey on, outcompete or hybridize with existing biota, becoming weeds or pests in agricultural systems (Thuiller 2007; Walther et al. 2009; Chown et al. 2012).

Despite successful range shifts being problematic in some cases, failure to track shifting climates also poses new and serious risks to species and ecosystems. Species for which dispersal is limited by natural barriers (e.g. island endemics), anthropogenic barriers (e.g. transformed land), their inherent biological characteristics (e.g. morphological, behavioural or physical traits), disappearance of suitable climate conditions, or their reliance on other organisms or habitats that shift at different rates, are at heightened risk of extinction (Root & Schneider 2006; J. W. Williams & Jackson 2007; S. E. Williams et al. 2008; Thomas et al. 2010). Range shift limitations can be further exacerbated by human responses to climate change, for example construction of dams and changing land use (Kostyack et al. 2011).While some evidence suggests that species are keeping up with their shifting climatic conditions (Chen et al. 2011; Gregory et al. 2009; Tingley et al. 2009), it remains to be seen whether this pattern will manifest globally and across all species groups. In large regions, particularly in the tropics, climate change is predicted to generate conditions unlike any occurring today (J. W. Williams et al. 2007); the risks and ecological implications of species reshuffling into novel, no-analogue communities are, as yet, unknown (Root & Schneider 2006; J. W. Williams & Jackson 2007).

Current legal frameworks and conservation strategies face the challenges of untangling desirable species range shifts from undesirable invasions, and identifying circumstances when movement should be facilitated versus inhibited. New agreements may be needed to regulate new or altered national trans-boundary migration, for example under the Convention of Migratory Species. As target species and ecosystems move, protected area networks will become less effective for conserving them, necessitating re-evaluation and adaptation, including possible addition of sites, particularly those important as either ‘refugia’ or migration corridors (Willis & Bhagwat 2009; Hole et al. 2011; Hannah 2011). Assisted colonisation – moving individuals or populations from currently occupied areas to locations with higher probability of future persistence – is emerging as a conservation tool for species that are unable to track changing climates themselves (Hoegh-Guldberg et al. 2008; Richardson et al. 2009; Thomas 2011). At this stage, however, difficulties in predicting target species’ invasiveness, in combination with economic constraints to implementation, continue to impede its acceptance (Loss et al. 2011). E*x situ* collections (i.e. in zoos, botanical gardens, and seed and gene banks) are often seem as a fall-back resource for conserving threatened species, yet their relatively low representation of global species and genetic diversity (Wyse-Jackson 2002; FAO 2010; Conde et al. 2011) limits the tools available to prevent extinctions of dispersal-limited species.

19.4.3. Indirect, Trans-Boundary, and Long-Distance Impacts of Mitigation Measures

Mitigation, too, can have unintended consequences beyond its boundaries. If mitigation involves a form of land use change, then regional implications can ensue in the same way as they can for adaptation (see 19.3.2.5).

19.4.3.1. Effects on Biodiversity

Mitigation reduces climate change impacts on biodiversity (Warren et al., 2012, ten Brink et al., 2010). However, the impacts on biodiversity as a result of habitat destruction concomitant to widespread implementation of land intensive biofuel production would offset any gains from the resulting reduction in climate change (ten Brink et al. 2010, Sala et al 2009). Second generation bioenergy, or use of degraded land, has a smaller impact (Searchinger et al 2008, van Oorschot et al 2010). It is possible to further offset losses due to land use change by increasing agricultural productivity, thus reducing some of the competition for land use. Tropical forest, in particular, can also be preserved under biofuel cropping strategies if the climate mitigation policy applied incorporates an economic price for emissions from land use change (Thomson et al 2010). PinKoh (2007) suggests that the oil-yield efficiency of major biodiesel feedstocks could be increased in order to reduce the pressure on land. Further details on these interactions from a sectoral perspective are found in 19.3.2.2.

Climate change mitigation through ‘clean energy’ substitution may also have a profound negative impact on biodiversity where it involves the construction of capital-intensive large hydroelectric dams, which will impact both terrestrial ecosystems within the hydroelectric reservoir and surrounding areas and aquatic ecosystems far downstream and far upstream along a river system (World Commission on Dams 2000). These impacts on biodiversity may include high deforestation rates in the surrounding landscape due to (i) new roads, power transmission lines, and new settlements to accommodate the large immigrant workforce involved in building large dams, (ii) mass tree mortality within low-elevation inundated areas, and (iii) discontinuity of upstream fish migrations (World Commission on Dams 2000; Bertham and Goulding 1997; Finer and Jenkins 2012; Anderson et al 2006). In all cases, low-lying forests and savannas are disproportionately affected by the direct and indirect impacts of building and maintaining a large dam. The biodiversity losses from large dams are particularly large relative to benefits of the dams in relatively flat lowland areas where the ecological effect size of dams — which is often expressed as the total inundated area (km^2) per unit of electricity produced (MW/yr) — tends to be very high. In addition to a wide range of ecological impacts, local indigenous populations are often displaced from their traditional territories within the reservoir area and immediate vicinities — in direct contradiction of the UN Declaration of Indigenous Rights (UN General Assembly 2007). In sum, there is a wide range of detrimental biodiversity, carbon storage and socioeconomic consequences of augmenting hydropower generation, especially in tropical countries, all of which require large dams to be reconsidered as low-impact energy sources.

19.4.3.2. Effects on Human Systems

Mitigation strategies will have a range of effect on human systems, dependent on the type of mitigation strategy as well as the type of human system. Even within a particular mitigation strategy, effects may vary considerably. Reforestation that properly mimics existing forest ecosystems in structure and composition would potentially benefit human systems by stabilizing micro-climatic variation. It would also provide numerous benefits from the sustainable harvest of non-timber forest products (NTFP’s) for food, medicine and other marketable commodities. However, there is a generally longer time frame and greater expense involved in recreating a diverse forest system. In the future, the short-term benefits from planting monoculture stands of tree species most beneficial for climate mitigation may win out over more complex reforestation efforts. In this scenario, human systems may still benefit from improved local climate effects but not benefit from the utilization of species in a diverse forest system. A current example of this is found in China where the world’s largest reforestation effort has led to dense monoculture stands of fast growing tree species through the Three Norths Shelterbelt Development Program (Zhang and Song 2005). Afforestation (foresting an area that was historically not forested) creates a similar set of costs and benefits.

In both reforestation and afforestation, land tenure and ownership becomes an issue for human systems. Relocation of human populations from agricultural lands in order to reforest would have negative consequences for those affected unless clear and thoughtful strategies are implemented. In this scenario, it would be necessary to "mitigate" the effects on human systems caused by climate mitigation. Efforts to preserve existing forests would have an overall benefit for human systems since over the long term, the costs to maintain an intact forest are much lower than the cost to restore a forest. Human populations utilizing NTFP's may continue to benefit as long as such utilization is carefully monitored for sustainability [CITES].

More generally, mitigation strategies designed to reduce dependence on carbon-intensive fuels present a very different set of circumstances in relation to human systems. The development of alternative and renewable energy sources will have significant economic and market effects which could influence food prices (see also 19.3.2.2.2). Some scenarios suggest a rise in energy costs solely due to the lower flexibility of renewable energy resources compared to fossil fuels, which would in turn affect prices in the energy-dependent agriculture sector. This would especially affect marginal populations who already devote a considerable portion of their household income to food. [CITE]

19.4.3.3. Indirect Effects of Biofuels Production via Markets

Biofuels increase the demand for the commodities (feed stocks) they are produced from. This increase in demand can be met in one of two ways: either through reduction in other demands for the commodity or an increase in the supply of the commodity, both of which will happen as the price starts to rise in response to biofuel production. For example, as the price of maize starts to rise, both humans and animal feedlots will reduce their use of maize, while farmers have an incentive to plant more acres and increase the supply. The size of the price increase depends on the demand and supply elasticities. The more elastic the supply or demand, i.e., the larger the change in quantity for a given change in price, the lower will be the resulting price increases. By the same token, the share that is met through a reduction in demand versus an increase in supply depends on the relative size of the elasticities. If the supply elasticity is twice as elastic as demand, two thirds of the biofuel mandate will be met through new production and one third through a reduction in demand.

Biofuels divert a significant share of global food production. For example, the 2009 US renewable fuel standard requires that 9 billion gallons of ethanol be blended into gasoline. Using an average conversion ratio of 2.7gallons/bushel (Rajapol et al., 2007), the mandate diverts roughly 25% of US maize production[1], or 11% of global maize production to biofuels.[2] Estimates of the supply and demand elasticity of basic grain commodities (Roberts and Schlenker 2009) lead to a prediction that the 2009 Renewable Fuel standard will increase commodity prices of maize, wheat, rice, and soybeans by roughly 20%, assuming one third of the calories used in ethanol production can be recycled as feedstock (Roberts and Schlenker 2010). On the other hand, second generation biofuels that can be grown on areas that are not suitable for commodity crops might induce less of a price effect if they do not directly compete for the same land.

[FOOTNOTE 1: US maize production averages around 12.5 billion bushels in 2007-2011 (www.nass.usda.gov).]

[FOOTNOTE 2: US maize production constitutes 42% of global maize production (www.faostat.fao.org).]

The increase in commodity prices will give farmers an incentive to increase supply around the globe, and thereby have the indirect effect of increasing CO2 emissions by an amount which remains uncertain. The central question is how much of the additional supply will come from the intensive margin (higher yields per acre), and how much will come from the extensive margin (more acres). Keeney and Hertel (2009) argue that yields respond to prices, yet Roberts and Schlenker (2010) find that historically the growing area adjusted in response to exogenous price shocks. Additional supply mainly comes from planting additional acres, raising the question of where the additional acreage would come from. On the one hand, Fargonie et al. (2008) and Searchinger et al. (2008) find large CO2 effects of indirect land use change. Deforestation would result in large indirect CO2 emissions, as does the production of biodiesel using palm oil on peatlands that are drained (Miettinen, 2012). On the other hand, a study of biofuel production in Brazil (Barr et al. 2011) finds that once pasture land is incorporated in the analysis, expansion into unexploited land is minor, i.e., most of additional cropland is predicted to come from conversion of pastureland. To the extent that biofuel feed stock is grown on areas that were previously fallow, the indirect land effects would further reduce CO2 emissions.

19.5. Other Emergent Risks

Most emergent risks appearing recently in the literature are related to multiple interacting systems and stresses (section 19.3) or to indirect and long-distance impacts (section 19.4). However, an additional set of risks have emerged related to particular biophysical impacts of climate change, including large temperature rise, ocean acidification, and CO2 increases, and to the potential consequences of geo-engineering as a climate change response strategy.

19.5.1. Risks from a Large Temperature Rise

Most climate change impact studies have been based on climate change scenarios corresponding to global mean temperature rises of up to 3.5°C relative to 1990 (or 4°C above pre-industrial levels) (Parry et al. 2004, Hare 2006, Warren et al. 2006, Fischlin et al. 2007, Easterling et al. 2007; [CITES]). Recently the potential for larger amounts of warming has received increasing attention in the literature, motivated by the possibilities that future radiative forcing could be higher than typically considered and that positive feedbacks between climate and the carbon cycle could be strong (Betts et al. 2011; Sanderson et al., 2011).

Emerging risks associated with warming greater than 4 C above pre-industrial include the potential exceedance of human physiological limits in some areas for a global temperature rise of 7°C above pre-industrial (Sherwood & Huber 2011); the triggering of non-linear earth system responses (Lenton et al 2007, see section 19.6.3.5); widespread disruption of ecosystem function and services, alongside projected extinction of a large proportion of the earth's biodiversity (Thomas et al 2007, Warren et al submitted) with potentially very large impacts on human systems and the economy [CITE]; large increases in the proportion of the population exposed to water stress, fluvial and coastal flooding, and hunger, especially in Africa (Sissoko et al 2010, Mougou et al 2010); the large investments that would be required for adaptation; and the aggregate impacts of climate change on the economy (see 19.6.3.4).

[INSERT TABLE 19-2 HERE
Table 19-2: Key risks from large temperature rise. (to be provided with SOD)]

19.5.2. Risks from Ocean Acidification

Ocean acidification is defined as "a reduction in pH of the ocean over an extended period, typically decades or longer, caused primarily by the uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the oceans" (Feely *et al.*, AR5 WG1 Ch. 3). It is a physical impact resulting from CO2 emissions that poses emerging risks to marine ecosystems and societies that depend on them. Ocean acidification is a relatively new research area, and the potential for associated risks to become key is magnified by the fact that it is a global phenomenon and, without a decrease in atmospheric CO2 concentration, it is irreversible on century timescales.

It is *virtually certain* that ocean acidification is occurring now (Dore *et al.*, 2009; Byrne *et al.*, 2010; Table 3.7.1 of AR5 WG1 Ch. 3). The upper mixed layer of the ocean, which is in direct contact with the atmosphere, has experienced a decline in pH that is consistent with predictions of about 0.1 pH unit since the preindustrial (Feely *et al.*, 2004). Because acidification is thermochemically driven by the difference in partial pressures of CO2 in the atmosphere and the ocean (Takahashi *et al.*, 2009), it will continue to increase in magnitude as long as the atmospheric CO2 concentration increases (National Academy of Sciences, 2010). For example, if atmospheric CO2 concentration were to reach 800 ppmv, average pH of the surface waters would be expected to decrease by an additional 0.3 units (Feely *et al*., 2009; Feely *et al*. AR5 WG1 Ch. 3). Ocean acidification of deeper layers is also occurring, but at rates dependent on ocean mixing (Caldeira and Wickett 2005; Ilyina *et al*., 2009).

Characterizing the risks of ocean acidification to marine organisms, populations, communities, ecosystems, and fisheries is limited by the complexity of interactions across these scales and the relatively small number of studies available for quantitative risk assessment. The degree of confidence in assessing the implications of ocean acidification decreases along the chain of consequences from biogeochemical processes to organisms to ecosystems to ecosystem services. The risks to many marine processes that directly affect organisms can be assessed with a medium degree of confidence.

A recent statistical meta-analysis of more than 70 laboratory studies across multiple taxa concluded that ocean acidification will have overall negative effects on organism growth, calcification, reproduction, and survival, but with a high degree of variation across taxa (Kroeker *et al*., 2010). Ocean acidification can also affect the availability of iron for marine photosynthesis, the rate of nitrogen fixation in several important cyanobacteria (Barcelos e Ramos *et al*., 2007, Hutchins *et al*., 2007, Kranz *et al*., 2010, Kranz *et al*., 2009, Levitan *et al*., 2007) as well as the rate of denitrification (Beman *et al*., 2011), and the chemical state and toxicity of some metals (Millero *et al*., 2009). Most of these processes can pose emerging risks because they affect marine organisms, ecosystems, food webs, fisheries, and biogeochemical cycling (National Academy of Sciences, 2010) (Figure 19-2).

[INSERT FIGURE 19-2 HERE
Figure 19-2: Assessment of impacts of ocean acidification on marine organisms through effects on various biogeochemical processes Assessment based on (1) estimated likelihood that the process will be affected by ocean acidification and (2) the magnitude of impacts to marine organisms. The width of the boxes roughly indicates the uncertainty in the likelihood of the process being affected by acidification, while the height of the boxes roughly indicates the magnitude of impacts to marine organisms. Height, width, and location of boxes are based on expert opinion, with greatest subjectivity in judging impacts. Judgments are based on impacts expected with atmospheric CO2 levels of 2-3x preindustrial levels (560-840 ppmv). This figure is meant to be broadly illustrative: with sufficient information Low, Medium, and High would be defined quantitatively. For example, while the sign of the impact on marine calcifiers is negative, the magnitude varies considerably across taxa and currently overall quantification is not feasible (based on a meta-analysis by Kroeker et al. 2010).]

As indicated in Figure 19-2, changes in marine calcification are *likely* and the overall magnitude of impact to calcifiers will be medium to high. This judgment is based on studies such as those that examine responses of marine ecosystems to ocean acidification caused by natural carbon dioxide seeps (Hall-Spencer *et al*., 2008; Fabricius *et al*., 2011). These studies document significant changes in community composition, biodiversity, calcification rates, and recruitment of corals at pH levels of 7.8, the expected pH once atmospheric CO2 concentration reaches 750 ppmv. The latter study (Fabricius *et al*., 2011) showed that coral reef growth ceased completely at pH levels < 7.7 (at atmospheric CO2 concentration > 970 ppmv).

The risks to ecosystem services are less certain. A recent synthesis of the vulnerability of individual nations to reductions in the global mollusk harvest (Cooley et al. 2012) identified how changes in overall availability and nutritional value of desired mollusk species could impact their economies and food availability, while acknowledging the difficulty of directly linking ocean acidification to harvest; hence the emerging nature of this risk.

19.5.3. Risks from CO_2 Health Effects

There is increasing evidence that the impacts of elevated atmospheric CO2 on plant species will affect health via two distinct pathways: the increased production and allergenicity of pollen and allergenic compounds, and the nutritional quality of key food crops. The evidence for these impacts on plant species is increasingly robust and recent evidence in the public health literature points to the potential for these risks to be sufficiently widespread in geographical scope and large in their impact on human health to be considered an emergent risk.

Climate change is expected to alter the spatial and temporal distribution of several key allergen-producing plant species (Shea 2008), and increased atmospheric CO2 concentration, independent of climate effects, has been shown to stimulate pollen production (Rasmussen 2002; Clot 2003; Galán 2005; García-Mozo et al. 2006; LaDeau and Clark 2006; Damialis et al. 2007; Frei and Gassner 2008). Ziska et al. (2000, 2003, 2012) found an association between elevated CO2 concentrations and temperature with faster growing and earlier flowering ragweed species (Ambrosia artemisiifolia) along with greater production of ragweed pollen (Wayne et al. 2002; Singer et al. 2005; Rogers et al. 2006) leading, in some areas, to a measurable increase in hospital visits for allergic rhinitis (Breton et al. 2006). Experimental studies have shown that poison ivy, another common allergenic species, responds to atmospheric CO2 enrichment through increased photosynthesis, water use efficiency, growth, and biomass. This stimulation, exceeding that of most other woody species, also produces a more potent form of the primary allergenic compound, urushiol (Mohan et al. 2006).

While climate change and variability is expected to affect crop production (see Ch. 7), emerging evidence suggests an additional stressor on the food system: the impact of elevated levels of CO2 on the nutritional quality of important foods. A prominent example of the effect of elevated atmospheric CO2 is the decrease in the nitrogen (N) concentration in vegetative plant parts as well as in seeds and grains and, related to this, the decrease in the protein concentrations (Cotrufo et al., 1998; Taub et al., 2008;Wieser et al., 2008). Experimental studies of increasing CO_2 to 550 ppm demonstrated effects on crude protein, starch, total and soluble B-amylase, and single kernel hardiness, leading to a reduction in crude protein by 4 to 13% in wheat and 11 to 13% in barley (Erbs at el, 2010). Other CO2 enrichment studies have shown changes in the composition of other macro- and micronutrients (Ca, K, Mg, Fe, Zn) and in concentrations of other nutritionally important components such as vitamins and sugars (Idso and Idso, 2001). The declining nutritional quality of important global crops is an emerging risk that has the potential to broadly affect rates of protein-energy and micronutrient malnutrition in vulnerable populations. While this emergent risk has the potential to become key, there is currently insufficient information to assess the likelihood that it will become key, or under what ambient CO2 concentrations that this risk will manifest as key.

19.5.4. Risks from Geo-Engineering (Solar Radiation Management)

Geoengineering can be defined as deliberate large-scale efforts to manipulate physical, chemical, or biological aspects of the climate system to counteract the consequences of increasing greenhouse gas emissions (IPCC, 2011). Geoengineering is distinct from mitigation, in that mitigation aims to reduce or prevent actions that would change the climate, such as emissions of gases and particles and changes to the land surface, while geoengineering involves deliberate changes to the climate system itself. It is an emerging risk both because it poses risks to society and ecosystems that could be large and widespread and because, although it is not a new idea (Rusin and Flit, 1960; Environmental Pollution Panel, 1965; Budyko, 1974, 1977; Cicerone et al., 1992; Panel on Policy Implications of Greenhouse Warming, 1992; Leemans et al., 1996; Dickinson, 1996; Schneider, 1996; Flannery et al., 1997; Teller et al., 1997, 2000, 2002; Keith, 2000, 2001; and a long history of geoengineering proposals as detailed by Fleming, 2004, 2006, 2010), it has received increasing attention in the recent scientific literature, stimulated in part by suggestions that nations consider geoengineering solutions to global warming in light of the absence of comprehensive global abatement policy (Crutzen, 2006; Wigley, 2006).

Geoengineering has come to refer to both carbon dioxide concentration reduction and solar radiation management (SRM; Shepherd et al., 2009; Lenton and Vaughan, 2009), and these two different approaches to climate control raise very different scientific, ethical (Morrow et al 2009) and governance issues (Lloyd and Oppenheimer 2012). Only SRM is discussed here, and unless otherwise noted, the term geoengineering will refer to SRM. Furthermore, although various SRM schemes have been suggested, we focus on stratospheric aerosols and marine cloud brightening as the only two schemes that seem to have the potential to produce effective and inexpensive large cooling of the planet (Lenton and Vaughan, 2009; Salter et al., 2008; McClellan et al., 2010).

Cloud brightening requires the introduction of salt or other cloud condensation nuclei into marine stratus clouds to induce the first indirect effect (Twomey effect – see AR5 WG I, Chapter 7) producing more, but smaller cloud droplets, enhancing the cloud-top albedo, while not producing other effects that reduce the total cloud amount (Wang et al., 2011). Stratospheric aerosols require injecting sulfate aerosol precursors into the lower stratosphere using airplanes or other means (Robock et al., 2009; McClellan et al., 2010) to increase planetary albedo and reduce incident solar radiation. Much more work is needed on the physical mechanisms associated with both proposed schemes before we can say if SRM is physically and economically feasible (IPCC, 2011) but for the purpose of this section, we assume that both approaches are, and we assess the risks of employing them.

SRM would produce both benefits and risks (Robock, 2008b; Robock et al., 2009). Benefits include cooling the planet, reducing or reversing melting of sea ice and ice sheets, increasing plant productivity and the terrestrial CO_2 sink, beautiful red and yellow sunsets, and potentially, control of regional precipitation. Risks include undesirable regional changes in climate; effects on ecosystems, stratospheric ozone, and tropospheric chemistry; implications for mitigation strategies, including rapid warming if stopped; effects of weaker solar radiation on solar electricity generation and passive solar heating; effects on airplanes, satellite remote sensing, and electrical properties of the atmosphere; as well as a number of other effects.

Approaches to assessing these risks include climate modeling as well as studies of volcanic eruptions and ship tracks. Observations of volcanic eruptions indicate that while stratospheric aerosols can reduce the global average surface air temperature, they can also produce regional drought much like that depicted in Figure 19-3 (e.g., Trenberth and Dai, 2007), cause ozone depletion through heterogeneous reactions on sulfate aerosols (Solomon, 1999), and change the ratio of diffuse-to-direct downward solar radiation, producing an increased carbon sink in the land biosphere and reducing electricity generation from solar generators that use focused direct sunlight (Murphy, 2009). Ship track observations are indeterminate due tof the difficulty of separating clear bright stripes in satellite images from the larger more diffuse cloud field that may also have an aerosol effect (e.g., Schreier et al., 2007; Capaldo et al., 2009; Peters et al., 2011).

[INSERT FIGURE 19-3 HERE
Figure 19-3: Northern Hemisphere summer precipitation differences from the current climate averaged for the second 10 years of a 20-year geoengineering period emitting 5 Mt SO_2 per year into the tropical lower stratosphere combined with A1B (Fig. 8, Robock et al., 2008). Hatch marks indicate changes significant at the 5% level. Note large reductions over India and China.]

Climate modeling studies of stratospheric sulfate aerosol approaches indicate unintended and possibly harmful impacts on the hydrologic cycle and ozone depletion (Robock et al., 2009). However, there is little agreement across studies on the magnitude and regional pattern of these consequences, because studies have not assessed comparable geoengineering scenarios. Some studies have injected similar amounts of SO2 into the stratosphere, but with different regional distributions (Robock et al., 2008; Rasch et al., 2008; Jones et al., 2010). Others have approximated net effects of stratospheric aerosols on the planetary energy balance by reducing the solar constant (Govindasamy and Caldeira, 2000; Govindasamy et al., 2002, 2003; Matthews and Caldeira, 2007; Bala et al., 2008). Studies have also differed in assumptions about anthropogenic greenhouse forcing (Robock et al., 2008; Jones et al., 2010; Ammann et al., 2010).

Cloud brightening would be expected to reduce global average temperature, but there would be large regional differences in responses. Jones et al. (2009), for example, found a large reduction of precipitation over the Amazon as a result of brightening clouds in the South Atlantic. However, modeling studies (Jones et al., 2009; Rasch et al., 2009; Partenan et al., 2012) are difficult to compare given model differences in the locations of marine stratus clouds.

With either sulfate aerosol or cloud brightening approaches, globally averaged precipitation is expected to be reduced as a consequence of reduced solar radiation, but the regional patterns of such a reduction are model-dependent (Bala et al., 2008). Some studies find that stratospheric geoengineering would reduce summer monsoon rainfall relative to current climate in Asia and Africa (Figure 19-3), potentially threatening the food supply for billions of people (Robock et al., 2008; Jones et al., 2010), but others find different regional patterns (Rasch et al., 2008). Past large volcanic eruptions have disrupted the summer monsoon (Oman et al., 2005; Trenberth and Dai, 2007) and even produced famine (Oman et al., 2006), but direct comparisons between geoengineering with stratospheric sulfate aerosols and large volcanic eruptions are limited by the differences in forcing. Some unanswered questions include whether a continuous stratospheric aerosol cloud would have the same effect as a transient one and to what extent regional changes in precipitation would be compensated by regional changes in evapotranspiration. Ozone depletion via heterogeneous chemistry on stratospheric aerosol particles is also a concern (Tilmes et al., 2008, Robock, 2008a; Rasch et al., 2008).

A model comparison project currently underway, the Geoengineering Model Intercomparison Project (GeoMIP; Kravitz et al., 2011), aims to produce results regarding the consequences of SRM that are comparable across models by carrying out a set of standardized experiments. Few results are available so far (Schmidt et al., 2012).

19.6. Key Vulnerabilities, Key Risks, and Reasons of Concern

In this section, we present key vulnerabilities, key risks, and emergent risks that have been identified by many of the chapters of this report based on the material assessed by each. We then discuss dynamic characteristics of vulnerability and risk, features which depend on future development pathways. After reviewing and updating the Reasons For Concern in light of literature since AR4, we reinterpret them to be consistent with the framework of evolving risk adopted in this chapter.

The examples in Table 19-3 are based on a selection from a larger number provided by the chapters of this report. In order to present an overview of the implementation of the risk framework used in this chapter, examples were selected to represent different thematic dimensions and key risks that are linked to different physical impacts and various key vulnerabilities.

[INSERT TABLE 19-3 HERE
Table 19-3: A selection of the physical impacts or other hazards, key vulnerabilities, key risks, and emergent risks based on the judgments of authors of various chapters of this report, utilizing the framework and systematization described in 19.2. The table indicates how these four categories are related as well as how they differ. The table is illustrative rather than comprehensive, aiming to show some examples of how of the framework may be applied across different themes and topics in the chapters. In addition to these examples, key risks may also arise from moderate vulnerability interacting with a very large physical impact.]

19.6.1. Key Vulnerabilities

Several of the risks noted in Table 19-3 arise because vulnerable people must cope and adapt not only to changing climate conditions, but to multiple, interacting stressors simultaneously (see 19.4), which means that effective adaptation strategies would address these complexities and relations. For example, the complex interactions of stressors related to crop failure and famine include changing rainfall patterns, high dependence on rain-fed agricultural in some regions with little access to alternative livelihoods, and limited coping and adaptive capacities. These conditions periodically coincide with high global food prices that could in combination trigger crises.

19.6.1.1. Dynamics of Vulnerability

This sub-section deals with the meaning and the importance of dynamics of vulnerability, while section 19.6.1.3 assesses recent literature and data regarding observed trends of vulnerability mostly at a global or regional scale. The literature provides increasing evidence that structures and processes that determine vulnerability are dynamic and spatially variable (IPCC 2012; and section 19.6.1.3). The IPCC SREX report states with *high confidence* that vulnerability and exposure of communities or social-ecological systems to climatic stressors and climate related extreme events are dynamic, thus varying across temporal and spatial scales due to influences of and changes in social, economic, demographic, cultural, environmental and governance factors (IPCC 2012, p. 7).

Examples of such dynamics in exposure and vulnerability encompass, e.g. population dynamics, such as population growth and increasing exposure of people and settlements in low lying coastal areas in Asia (see Nicholls and Small 2002; Levy 2009; Fuchs/Conran/Louis 2011). Demographic changes, such as aging societies, have a significant influence on vulnerability to heat stress (see Staffogia et al., 2006; Gosling et al., 2009). Changes in poverty or socio-economic status, race-ethnicity compositions as well as age structures had a significant influence in past crises and disasters triggered by climate and weather related hazards. Cutter and Finch (2008) found that social vulnerability increased over time in some areas of the United States due to changes in socio-economic status, race-ethnicity composition, age, and density of population. Such factors had a direct influence on the vulnerability of people exposed to the Hurricane Katrina disaster (Cutter and Finch (2008). Changes in the strength of social-networks (e.g., resulting in social isolation of elderly) and physical abilities to cope with such extreme events modify vulnerability (see e.g. Khunwishit 2007).

Important dynamics of human vulnerability have also been observed in the context of extreme impacts and disasters. In some case human vulnerability might also change in different phases of crises and disasters. Hence, the factors that might determine vulnerability before the disaster might differ from those that determine vulnerability thereafter (post-disaster and recovery phases). The Indian Ocean Tsunami provides an example where disaster as well as the disaster response and reconstruction processes and policies modified the vulnerability of coastal communities (Birkmann and Fernando 2008). Overall, these examples underscore that a comprehensive assessment of vulnerability would account for these dynamics. This also requires an improved assessment of long-distance impacts (e.g., resulting from migration) and multiple-stressors (e.g. climatic stressors, recovery policies after disasters, etc.) that often influence these dynamics.

The following subsection deals in greater depth with the phenomena of differential vulnerability based on recent literature.

19.6.1.2. Differential Vulnerability

Wealth, education, race, ethnicity, religion, gender, age, class/caste, disability, and health status can illustrate and contribute to the differential vulnerability of individuals or societies to climate and non-climate related hazards (see IPCC 2012). Differential vulnerability is, for example, revealed by the fact that people and communities that are similarly exposed face different levels of harm, damage and loss as well as success of recovery. The uneven effects and the uneven suffering of different populations groups and particularly marginalized groups is well documented in various studies and in the scientific literature (Kasperson and Kasperson 2001; Bohle et al., 1994; Thomalla et al., 2006, Birkmann 2006). Factors that determine and influence these differential vulnerabilities and exposure patterns to climate change and climate related hazards encompass for example race and ethnicity (Elliot and Pais, 2006; Fothergill et al., 1999; Cutter and Finch, 2008), socioeconomic class (O'Keefe et al., 1976; Peacock et al., 1997; Ray-Bennet, 2009), gender (Sen, 1981), age (Bartlett, 2008; Jabry, 2003; Wisner, 2006b) as well as migration experience (Cutter and Finch, 2008) and homelessness (see Wisner 1998) (see IPCC 2012). These differential vulnerabilities are often attributed to specific populations at a particular scale. While local scale approaches can assess a variety of quantitative and qualitative measures, global and national assessments are often based on existing quantitative data (see Cardona 2006; 2008; Birkmann et al. 2011). In this context the usefulness of the specific approach, method and indicators depends on the function and the application are of the approach (Cardona et al., 2003a; Carreño et al., 2007b). In general larger aggregations of population groups and resulting generalizations require careful interpretation in terms of the actual vulnerability of specific populations (Adger and Kelly, 1999). Furthermore, the scientific literature underscores that groups which are marginalized, particularly due to gender or wealth status, are differentially affected by physical impacts of climate change in terms of both gradual changes in mean properties as well as extreme events (e.g., Neal and Phillips, 1990; Enarson and Morrow, 1998; Neumayer and Plümper, 2007). This body of literature is relatively recent, particularly in a developed world context, compared to the longer recognition of gender concerns in the development field (Fordham 1998). Gendered vulnerability in which women and girls are often (although not always) at greater risk of dying in disasters, is not solely linked to the physical conditions, but rather determined by their being typically marginalized from decision making fora, and discriminated and acted against in post-disaster recovery and reconstruction efforts (Houghton, 2009; Sultana, 2010). Hence, vulnerability in terms of gender is not determined through biology, but in most cases by social structures, institutions and rule systems (IPCC 2012).

Overall, the research findings and evidence regarding differential vulnerability emphasizes the social construction of risk, meaning that climate change related physical impacts and stressors affect populations in ways that are particular.

19.6.1.3. Trends in Vulnerability

Vulnerability as well as exposure of societies and social-ecological systems to physical impacts of climate change are dynamic and depend on economic, social, demographic, cultural, institutional, and governance factors (see IPCC 2012, p.7). Population growth, rapid and unsustainable urban development, international financial pressures, increases in socioeconomic inequalities, trends and failures in governance (e.g. corruption), and environmental degradation are trends that modify vulnerability of societies and communities (Maskrey, 1993a,b, 1994, 1998; Mansilla, 1996; Cannon, 2006) at different scales. Consequently, many of the factors that reveal and determine differential vulnerability, such as socio-economic status, wealth, poverty, age, health conditions or migration experience and governance processes (see 19.6.1.2) are dynamic, often changing over time in terms of their spatial distribution. For example, wealth and its distribution, education, demography, health status and governance issues are not solely characteristics that can be assessed at a particular time using widely agreed indicators, such as the GINI index or the illiteracy rate; rather trends in these indicators can also be observed. The following section assesses the knowledge base on observed trends in vulnerability, within the constraint that data for assessing such trends in vulnerability is still fragmentary and much of it only recently emerging.

The trends outlined below serve as an illustration of the dynamic nature of vulnerability. They are not intended to provide a comprehensive picture; rather they suggest for selected areas that the trends in the past in such indicators heavily influenced vulnerability. The assessment and illustration of trends is differentiated into 3 broader categories: I) trends in socio-economic, II) environmental and III) institutional vulnerability – which is closely linked with questions of governance. These vulnerability trends are also examined in order to assess their potential and actual overlap with climate related trends in order to determine risk.

19.6.1.3.1. Trends in socioeconomic vulnerability

Trends in poverty

Trends in poverty are arguably one of the key factors determining vulnerability of societies. Trends in poverty at the local, national and global level have fundamental influences on the general levels of vulnerability, since, in particular, poor and marginalized populations face severe difficulties coping or adapingt to additional stressors, such as climate change and its physical impacts, due to the constraints in resources and adaptation options. For example, past and recent trend analyses underscore that drought risk is intimately linked to poverty and rural vulnerability (see GAR 2011, p. 62). That means the risk of loss of livelihoods and harm due to droughts is heavily influenced by the poverty patterns of societies and communities exposed to drought, e.g. in Africa or Asia. Restocking by poor pastoralists' households in rural areas in Africa after a drought may take several years due to the limited financial resources (see in detail Chapter 13). Interestingly, recent global studies for 119 countries (thus accounting for approximately 95 percent of the global population) found that at the international level there is a clear decrease in global poverty over the past six years (Chandy and Gertz 2011). The number of poor people globally fell by nearly half a billion people, from over 1.3 billion in 2005 to under 900 million in 2010. This trend is expected to continue at least until 2015 (according to Chandy and Gertz (2011). While the poverty rate at the global level is decreasing and now accounts for approx. 16 percent of the total global population (in 2010), regional differences are significant. Particularly, the highly drought exposed region sub-saharan Africa still has nearly 47% of its population living in poverty, compared to an approximately 20% poverty rate in South Asia (poverty defined as people with less than 1.25 dollar per day). Accordinlgy, despite a global trend toward poverty reduction, there is a growing climate-related risk in sub-saharan Africa due to the high poverty rate in combination with projected increases in dryness in the region due to climate change (IPCC 2012, p. 15).

Trends in income distribution

Income distribution patterns are an important factor linked to vulnerability. Variation of the GINI index, a measure of income inequality, across selected countries in Africa, Asia, Latin America and Europe shows differential trends and patterns. For example, Africa six countries show a significant increase in the inequality of income distribution, while 13 countries show a reduced gap between rich and poor population groups. Increases in the GINI index can also be observed in China, India, Indonesia and Bangladesh (Worldbank 2012). These countries not only represent a large part of the world population, but are also highly exposed to climate change and respective hazards, such as sea-level rise in the case of Bangladesh and Indonesia (CIESIN et al. 2012; Birkmann et al. 2011) as well as droughts and floods in the case of India and China (see PREVIEW/UNEP 2012; CRED EM-DAT 2011). The increasing divide between poor and wealthy population groups in some countries could increase vulnerability, which in combination with climate related hazards could increase risk.

Trends in health

Health conditions of individuals and population groups affect vulnerability to climate change by limiting of coping and adaptive capacities to deal with additional stressors. Consequently, trends and conditions in the burden of disease and associated risk factors (Mather and Loncar, 2006) at a variety of geographical scales may affect local to global levels of vulnerability. The IPCC SREX report underscores, for example that obesity, a risk factor for cardiovascular disease, is increasing in a number of countries (Skelton et al., 2009; Stamtakis et al., 2010), increasing vulnerability of people to heat stress. Moreover, trends in HIV/AIDS, tuberculosis and malaria are also observed in regions that are highly exposed to climatic hazards, such as Africa and South-East Asia. Some countries exposed to these health risks also face significant limitations with regard to their health systems (Vitoria et al., 2009) and therefore malaria and HIV/Aids occasionally reach epidemic proportions with severe consequences for the ability of affected people to cope and adapt to additional climatic stressors.

Extreme heat events, characterized by consecutive days with abnormally high temperatures, are increasing in frequency, intensity, and duration (IPCC SREX 2012) signaling an emergent public health risk, particularly for urban populations. Advanced age represents one of the most significant risk factors for heat-related death (Bouchama and Knochel 2002). In addition to having diminished thermoregulatory and physiologic heat-adaptation ability, the elderly more often live alone, have reduced social contacts, and higher prevalence of chronic illness and poor health (Khosla and Guntupalli 1999; Klinenberg 2002; O'Neill 2003).

The prevalence of these social and physiological vulnerabilities to extreme heat will increase as global populations grow older. Aanalysis of global demographic trends for populations >60 years old indicate a substantial increase in both the absolute size of the elderly population as well as a potential doubling or tripling of these groups as a proportion of total population by 2100 (O’Neill, MacKellar, Lutz 2001). Another demographic trend affecting vulnerability to extreme heat is population movement towards urban areas, which are currently gaining an estimated 67 million people globally per year—about 1.3 million every week. By 2030, approximately 60% of the projected global population of 8.3 billion is expected to live in cities (United Nations 2006).

Urban areas are a largely transformed environment, from absence of native vegetation to an engineered infrastructure that increases thermal-storage capacity, resulting in significant change in the urban climate compared to adjacent rural regions, known as the Urban Heat Island effect (UHI). The combined effect of the high thermal mass provided by concrete and blacktop roads, the low ventilation ability of the urban “canyons” created by tall buildings, lower evapotranspiration due to replacement of soils by impermeable surfaces, and “point-source” heat emitted from vehicles and air conditioners, adds to the temperature increases created by climate change (Brazel 2005). In real terms, relative to the surrounding rural and suburban areas, the UHI can add from 2 – 10 degrees Fahrenheit to ambient air temperature (EPA 2005; Vose et al. 2004). More importantly, the UHI serves to absorb heat during the daytime and radiate it out at night, raising the nighttime minimum temperatures, which have been epidemiologically linked with excess mortality (EPA 2006).

Absent a sufficient increase in generating capacity, the projected increase (IPCC 2012) in the magnitude and duration of extreme heat events (EHEs) would increase electrical demand for air conditioning during EHEs, severely taxing the power grid infrastructure leading to rolling brown-outs or a large-scale power failure (Vine 2012). Model projections of increases in extreme heat events and electrical demand for air conditioning indicate that under a variety of assumptions, cities experience electricity deficits during peak demand periods (Miller et al. 2008). Electricity deficits during heat waves remove one of the most effective health interventions for heat-related illness and death, access to an air-conditioned environment (Luber and McGeehin 2008).

Urbanization

In addition projected increase in the fraction of the population which is urbanized, the sheer numbers of urban dwellers will represent a large pool of potentially vulnerable individuals, concentrated into relatively small areas. The modification of environmental processes by urbanization in combination with increasing exposures to climatic stressors, such as floods, flash floods or heat waves, may enhance the vulnerability of urban populations. Urban megacities in developing countries and countries in transition are particularly complex systems characterized by highly interwoven processes and rapid changes, while at the same time formal planning tools and measures often cannot cope with the variety of changes accompanying urbanizaton, e.g. the rapid growth of informal settlements and the resulting gap in provision of adequate infrastructure provision (Matthias and Coelho, 2007). These patterns of urbanization increase vulnerability and exposure of people to climatic hazards, particularly due to the fact that informal settlements are often located in hazard prone areas as well as due to the inadequate access to basic infrastructure services (such as water and sanitation) (see e.g. UN Habitat, 2003; Utzinger and Keiser, 2006). However, it is also important to note that urbanisation poses different implications for vulnerability (and adaptive capacity) in different regions depending on the broader context of the socio-economic development status and governance conditions (Garschagen and Kraas 2010; Birkmann et al. 2010). On the one hand, unplanned rapid urbanisation in many parts of the developing world exceeds the capacities of public authorities to provide sufficient infrastructures leading in general to increases in exposure and vulnerability; on the other hand, the contrary trend of shrinking urban density in some parts of Western Europe or Northern America may also lead to increased levels of vulnerability as social networks diminish and the efficiency of public infrastructures decreases.

19.6.1.3.2. Trends in environmental vulnerability

Ecosystem services

The environment provides a range of ecosystem services. These can be classed as provisioning (e.g. food and water), regulating (flood and disease control), supporting (e.g. biogeochemical cycling), and cultural (e.g. aesthetic, spiritual and recreational) (see e.g. MEA 2005). Environmental degradation and climate change will have a major impact on the quality and availability of such services. Particularly, societies and communities that heavily rely on the quality of ecosystem services, such as rural populations, are *very likely* to experience additional risks, for example due to the increasing loss of supportive services of ecosystems. Such loss of services I part-and parcel to urbanization as usually practiced; e.g., the loss of regulative services of soils and landscapes (e.g. buffer and filter function of soils and vegetation) in rapidly urbanizing areas in flood plains and delta regions exacerbates vulnerability to flooding in intense rainstorms.

Inevitably development pathways of societies and communities also influence the quality and degradation of environmental services and functions which provide an important resource base for human development. Approximately 90 percent of the world's poor have been estimated to be directly or indirectly dependent on forests for at least some of their income (World Bank 2002), while roughly 250 million people depend substantially on fisheries for food and income (MEA 2005). Hence, large proportions of the world's rural population – particularly in developing countries – depend on ecosystem services and functions. Consequently, projected physical impacts of climate change that modify and degraded these resource bases pose serious threats to human livelihoods and economies at a range of scales (IPCC SREX 2012). There are a number of current environmental trends that threaten human well-being and thus by extension human vulnerability (UNEP, 2007). Many communities have suffered considerable losses due to extreme weather events in combination with the degradation of ecosystems and ecosystem services, which have rendered them even more vulnerable to future climatic and non-climatic extreme events. For example, agricultural productivity, food security, livelihoods and health are being affected by land degradation which often starts with soil sealing, erosion, salinization, fire risk, over production, and land fragmentation resulting from both natural and human-caused changes in climate, soil, vegetation conditions and economic and population pressures (Salvati and Zitti, 2009). The extinctions of species and the loss of biodiversity pose a threat of diminution of genetic pools that otherwise buffer the adaptive capacities of social-ecological systems in the medium and long-run (e.g. in terms of medicine and agricultural production).

19.6.1.3.3. Trends in institutional vulnerability

Governance

Institutional vulnerability refers to issues of governance. Governance is an important factor that influences vulnerability and adaptive capacity of societies and communities as well as ecosystems exposed to climatic stressors and physical impacts of climate change. At a general level Kahn (2005) concludes that states with strong institutions and better governance face fewer deaths after extreme natural events than those with weak or absent institutions. Weak or failed governance is a driver of vulnerability due to the fact that those countries classified as failed states might not be able to guarantee their citizens basic standards of human security (see chapter 12). Secondly, weak governance influences coping and adaptive capacities of societies and communities exposed to extreme events and climate change related hazards (physical impacts) (WRI 2011). Although it is still difficult to measure aspects of governance at the national and international level that bear severe implications for the vulnerability to climate change, the Failed State Index (see Fund for Peace 2012 website; Foreign Policy 2012 website) as well as the Corruption Perception Index (see Transparency International 2012) are two indicators and data sets that provide initial insights into the issue. Trends in corruption - using the Corruption Perception Index - cannot be assessed for all countries due to data constraints; however, existing data for, e.g., 47 countries in Africa suggest that about 16 countries succeeded in reducing their level of corruption, while 24 countries show an increasing trends in corruption based on data from 1998 or 1999 to 2011 (see Transparency International 2012 website). In addition, the Failed State Index, based on expert surveys and the conflict assessment system tool (CAST) method, captures widespread violations of human rights, criminalization and de-legitimization of the state as well as massive movement of refugees or internally displaced persons creating humanitarian emergencies. Trends in the Failed State Index from 2006 up to 2011 show that countries with severe problems in the functioning of the state cannot easily shift or change their situation; However, as one example to the contrary, the Republic of Congo which ranked second in the world list of failed states in 2006 improved its situation significantly and ranked 32 in 2011. Indonesia, the Dominican Republic as well as Bosnia provide additional examples of significant improvement in terms of governance based on the Failed State Index (see Fund for Peace 2012 website). Despite these examples of improved governance and reduced institutional vulnerability, including some countries which are also highly exposed to climatic hazards, there remains a negative trend at the global level: in 2006 the Failed State Index pointed to nine countries that had severe problems in governance, and 13 such countries in 2011. Also the category below those countries with severe problems in governance increased from 28 countries in 2006 to 35 countries in 2011. Hence, at the global scale we observe an increase in countries with governance problems and conflicts that might also limit the capacity of states to effectively prepare and respond to climate change and climate variability. This is an alarming trend, since these countries are not in the position to support vulnerability reduction nor they can effectively support coping and adaptation processes of people exposed to climatic stressors. Countries s characterized in some literature as substantially failing in general governance or in some particular aspects of governance , such as Somalia and Sudan, Haiti or Pakistan have shown in the past severe difficulties in dealing with extreme events, such as severe droughts, storms or floods and complex emergencies (see e.g. Lautze et al. 2004; Ahrens and Rudolph 2006; in terms of Pakistan see Khazai et al. 2011, p. 30-31, in terms of Somalia see Menkhaus 2010, p. 320-341). Unless governance improves, an increase in risk is *likely* to occur as the climate changes.

19.6.1.4.Risk Perception

Risk perceptions influence the behavior of people in terms of risk preparedness and adaptation to climate change (IPCC 2012; Burton et al. 1993, van Sluis and van Aalst 2006). Factors that shape risk perceptions and therewith also influence actual and potential responses (and this vulnerability and risk) include a) interpretations of the threat, including the understanding and knowledge of the root cause of the problem, b) exposure and personal experience with the events and respective negative consequences, particularly recently (availability) c) priorities of individuals, d) environmental values and value systems in general (see e.g. O'Conner 1999; Weber 2006; Grothmann and Patt, 2005; Kuruppu and Liverman 2011). Furthermore, Weber (2010) argues that the perceptions of risk and reactions to such risk and actual events are also shaped by motivational processes (Weber, 2010). In this context people will often ignore predictions of climate change related stressors and extreme events if those predictions fail to elicit emotional reactions. In contrast, if the event or forecast of such an event elicits strong emotional feelings of fear, people may overreact and panic (see Slovic et al., 1982; Slovic 1993, 2010; Weber, 2006). Risk perceptions particularly influence and increase vulnerability in terms of false perceptions of security. The disastrous tsunami in Japan in March 2011 is one prominent example, where some coastal communities had a false sense of security due to the existing protection structures (e.g., 10m wall) that had served as effective risk reduction measures in the past during smaller tsunamis. Present risk management plans were developed using 400-year historical earthquake data and did not foresee the great magnitude of the seaquake in March 2011 (Sagiya,2011). The tsunami hazard was similarly underestimated (Hibbs 2012; Funabashi and Kitazawa 2012). Consequently, public perceptions of risks are not solely determined by the "objective" information, but rather are the product of the interaction of such information with social, institutional, and cultural processes and norms which are partly subjective (Kasperson et al., 1988). Studies about health, social psychology, and risk communication suggest that social and cultural risk amplification processes modify perceptions of risk in either direction and in ways that may generally be socially adaptive (APA, 2009; IPCC 2012). Finally, it is important to acknowledge that everyday concerns and satisfaction of basic needs may prove more pressing than attention and effort toward actions to address longer-term risks and changes in the light of climate change and risk (Maskrey, 1989, 2011; Wisner et al., 2004). Rather people's worldview and political ideology guide attention toward events that threaten their preferred social order (Douglas and Wildavsky 1982).

19.6.2. Key Risks

19.6.2.1. The Role of Adaptation and Alternative Development Pathways

As discussed in section 19.2.4, the identification of key risks depends in part on the underlying socio-economic conditions assumed to occur in the future, which can differ widely across alternative development pathways. Literature since the AR4 has begun to compare impacts across development pathways and also to compare the contributions of anthropogenic climate change and socio-economic development (through changes in vulnerability and exposure) to climate-related impacts. The relative importance of development and climate change varies by sector, region, and time period, but in general both are important to understanding possible outcomes.

For example, the impacts of climate change on food security and water stress have been found to be strongly dependent on socio-economic conditions. The effect of climate change on the number of people at risk from hunger generally spans a range of +/- 10-30 million across the four SRES scenarios, with the number rising to 120-170 million in some analyses based on the A2 scenario, which assumes high population growth (Schmidhuber & Tubiello, 2007). Climate change impacts on food consumption or risk of hunger have been found to be small relative to changes in these measures driven by socio-economic development alone (Nelson et al., 2010; Schmidhuber & Tubiello, 2007). Similarly, a global study of water stress found that population growth was the primary determinant of future water stress in a scenario in which global average temperature increased by 2 C (Fung et al., 2008). In a scenario with a 4 C increase, both climate change and population growth were important to determining outcomes.

Sea level rise impacts will also depend on development pathways, due to the effect of development on the exposure of both the population and economic assets to coastal impacts, as well as on the capacity to invest in protection (Anthoff et al., 2010). A study of Europe found that socio-economic development dominated coastal impacts over the first half of the 21st century, while over the second half both the amount of sea level rise and development were important (Hinkel et al., 2010). Projected changes in heat-related mortality in Europe by the 2080s have also been found to be driven nearly as much by changes in population and age structure as by climate change, and more so if the potential for acclimatization is taken into account (Watkiss & Hunt, 2012).

Assessments of the impacts of extreme events have also evaluated the role of development pathways. Several studies argue that potential future damages from tropical cyclones are largely driven by socio-economic changes such as growth in population and wealth, and much less by the climate change signal itself (Bouwer et al., 2007; Pielke Jr., 2007). Flood risk in Europe has been shown in some cases to be as sensitive to assumptions regarding future land use and distributions of buildings and infrastructure as it is to the climate change scenario assumed (Bouwer et al., 2010; Feyen et al., 2009). Climate change was the dominant driver when particular aspects of socio-economic development, such as buildings and infrastructure, were excluded from the analysis (Linde et al., 2011) or when biophysical impacts such as stream discharge, rather than its consequences, were assessed (Ward et al., 2011).

With few exceptions, most ecosystem impact studies do not account for changes in future socio-economic conditions (Warren et al., 2011). A study of land bird extinction risk found some sensitivity to four alternative land use scenarios, but risk was dominated by the climate change scenario (Sekercioglu, 2008). Similarly, a study of European land use found that while land use outcomes were more sensitive to the assumed socio-economic scenario, consequences for species depended more on the climate scenario (Berry et al., 2006).

Some studies have not accounted for future socio-economic change, but have evaluated the vulnerability of sub-groups of the current population to climate-related stresses, showing that socio-economic conditions are a key determinant of risks to low-income households due to climate change effects on agriculture (Ahmed et al., 2009; Hertel et al., 2010), to sub-populations due to exposure to heterogeneous regional climate change (Diffenbaugh et al., 2007), and to low-income coastal populations due to storm surges (Dasgupta et al., 2009). Assessments of environmentally induced migration have concluded that migration responses are mediated by a number of social and governance characteristics that can vary widely across societies (Warner, 2010; chapter 19.4.X). These studies find that variation in socio-economic conditions explain some of the variation in risks of associated with climate and climate change. They therefore support the idea that alternative development pathways, which describe different patterns of change in these conditions over time, should be expected to influence the future risks of climate change.

Explicit assessments of the potential for adaptation to reduce risks have been less common, but when undertaken have indicated substantial scope for reducing impacts of several types. Assessments of the impacts of sea level rise have begun to incorporate the possibility of adaptation through investing in coastal protection, as opposed to accommodation or abandonment strategies, and have indicated that protection, and therefore a substantial reduction in impacts, can be an economically rational response for large areas of coastline globally (Nicholls and Cazenave, 2010; Anthoff et al., 2010; Nicholls et al., 2008a, 2008b) and in Europe (Bosello et al., 2012). For example, a study of sea level rise impacts in Europe found that adaptation in the form of increasing dike heights and nourishing beaches reduced the number of people affected by coastal flooding by a factor of 110 to 228, and total economic damages by a factor of 7 to 9 (Hinkel et al., 2010). Nonetheless, in some areas with higher vulnerability such as low-lying island states and parts of Africa and Asia, impacts are expected to be greater and adaptation more difficult (Nicholls et al., 2011).

Similarly, the risk to food security could be reduced through policy and institutional reform, although most impact studies have focused on agricultural production and accounted for adaptation to a limited and varying degree (Ziervogel and Ericksen, 2010; Nelson et al., 2009; Lobell et al., 2008). A study of response options in Sub-Saharan Africa identified substantial scope for adapting to climate change associated with a global warming of 2 degrees C, given substantial investment in institutions, infrastructure, and technology, but was pessimistic about the prospects of adapting to a world with 4 degrees of warming (Thornton et al., 2011; see also section 19.6.1). A study focused on Europe identified improved water use efficiency and extension services as the highest priority agricultural adaptation options available in that regions (Iglesias et al., 2012).

_____ START BOX 19-3 HERE ____

Box 19-3. Illustrating the Shared Socioeconomic Pathways

A new generation of socio-economic and climate change scenarios is under development intended to serve as a shared point of reference across research communities. Climate change scenarios are being produced by the climate modeling community based on a set of four Representative Concentration Pathways (RCPs; Moss et al., 2007; 2010) that vary widely in level and rate of change of radiative forcing. In addition, a set of Shared Socio-economic Pathways (SSPs) is being developed that would characterize a wide range of possible development pathways (Kriegler et al., 2010; Van Vuuren et al., 2011; Arnell et al., 2011; O'Neill et al., 2012). The use of SSPs and RCPs (and climate model simulations based on them) to carry out scenario analyses is envisioned as having a matrix architecture, where each RCP could be used together with a range of SSPs, and similarly each SSP could be used in conjunction with multiple RCPs.

One of the key aims of the scenario matrix architecture is to facilitate research and assessment that can characterize the range of uncertainty in mitigation efforts required to achieve particular radiative forcing (or concentration, or emission) pathways, in adaptation efforts that could be undertaken in preparation for and response to the climate change associated with those pathways, and in residual impacts. All of these outcomes will be dependent on assumptions regarding future socio-economic conditions described in SSPs. To provide a basis for characterizing this uncertainty, SSPs are conceived of as being defined along two axes: socio-economic challenges to mitigation, and socio-economic challenges to adaptation (see Figure 19-4). Socio-economic challenges to mitigation are defined as consisting of two components: factors that tend to lead to high *reference emissions* in the absence of climate policy because, all else equal, higher reference emissions makes the accompanying mitigation task larger; and factors that would tend to reduce the inherent *mitigative capacity* of a society. Socio-economic challenges to adaptation are defined as societal conditions related to exposure, sensitivity, and adaptive capacity that, by making adaptation more difficult, increase the risks associated with any given climate change scenario.

[INSERT FIGURE 19-4 HERE
Figure 19-4: Definition of five Shared Socio-economic Pathways (SSPs) describing alternative development pathways that span a range of challenges to adaptation and mitigation (O'Neill et al., 2012).]

SSPs will include qualitative narratives and quantitative information that will help characterize the future in a way that will facilitate a wide range of studies at a variety of scales based on the SSPs, including integrated assessment modeling studies. Although specific SSPs are still under development (O'Neill et al., 2012), the definition of the principal axes along which they will vary is intended to facilitate research relevant to improving understanding of how alternative development pathways influence key risks, biophysical impacts, and vulnerabilities.

_____ END BOX 19-3 HERE ____

19.6.2.2. Relationship between Adaptation, Mitigation, and Residual Impacts at Regional and Sectoral Levels

[forthcoming]

19.6.3. Updating Reasons for Concern

The Reasons for Concern (RFCs) are five categories of impacts, or characteristics of impacts, that were introduced in the IPCC TAR (Smith et al., 2001) in order to facilitate interpretation of Article 2 by aggregating a wide range of individual consequences of climate change into a smaller number of broad categories. In AR4, new literature related to the five RFCs was assessed, leading in most cases to confirmation or strengthening of the judgments about their relevance to defining dangerous anthropogenic interference (Schneider et al., 2007; Smith et al., 2009). RFCs are related to the framework of key risks, physical impacts, and vulnerabilities used in this chapter because each RFC is understood to represent a broad category of key risks to society or ecosystems related to a specific type of physical impact (extreme events, large-scale singular events), system at risk (unique and threatened systems), or characteristic of risk to social-ecological systems (aggregate impacts on those systems, distribution of impacts to those systems). For example, the RFC for extreme events implies a concern for risks to society and ecosystems posed by extreme events, rather than a concern for extreme events *per se*. Because risks depend not only on physical impacts of climate change but also on vulnerabilities of societies and ecosystems to those impacts, RFCs as a reflection of those risks depend on both factors as well (see also 19.1).

19.6.3.1. Unique and Threatened Systems

Unique and threatened systems include a wide range of physical, biological, and human systems that are restricted to relatively narrow geographical ranges (Smith et al., 2001). Loss of or damage to such systems are key risks when these systems have great importance to other systems and to society, and because in some cases such loss or damage would be irreversible. AR4 stated with *high confidence* that a warming of up to 2°C above 1990-2000 levels would result in significant impacts on many unique and vulnerable systems, and would increase the endangered status of many threatened species, with increasing adverse impacts (and increasing confidence in this conclusion) at higher temperatures (Schneider et al., 2007).

Since AR4, there is new and stronger evidence to support this judgment, particularly regarding species and ecosystems. AR4 stated with *medium confidence* that approximately 20-30% of the plant and animal species assessed to date are at increasing risk of extinction as global mean temperatures exceed a warming of 2-3°C above pre-industrial levels (Fishlin et al. 2007). There is increased evidence of observed climate change impacts (including those arising from changes in climate variability) in ecosystems, including range loss in plants and animals and changes in phenology (Gange et al., 2007; PUdas et al., 2008; Moreno-Rueda et al., 2009; Furgal et al., 2009, Devictor et al., 2008; Kusano and Inoue, 2009; Beckage et al., 2008; Thibault and Brown, 2008; Kelly and Goulden, 2008; Foden et al., 2007), and upon ecosystem composition and function (Blaum et al., 2007; Le Roux and McGeoch, 2008; Vittoz et al., 2009). It has been suggested that an additional 10% of species are exposed to increased extinction risk for each 1°C increase in temperature (CBD, 2009). Recent work has highlighted that species which are widespread geographically are also at risk (Warren et al., submitted), not only endemics which have tended to be a focus of study until now, implying a greater risk to ecosystem service provision (Gaston 2008; Allesina et al., 2007). New work has exposed the potential for large turnovers in marine species in response to climate change, putting marine ecosystem functioning at risk (Cheung et al., 2009), and has identified tropical ecosystems (Deutsch et al., 2009; Wright et al., 2009; Kearney et al., 2009) and tropical island endemics (Fordham and Brook, 2010) as particularly vulnerable, alongside polar, coral reef, mountain (Colwell et al., 2008) and Mediterranean systems. Much new work has focused on synergistic impacts of climate-change induced increases in fire, drought, disease, and pests (Flannigan et al., 2009; Krawchuk et al., 2009; Hegland et al., 2009; Koeller et al., 2009; Garrett et al., 2011; Garamszegi, 2011), leading to the projection of more severe impacts than in AR4

Regarding physical systems, there is new evidence about the risks to glaciers and the human systems that their meltwater supports. Later this century, reduced meltwater flow from glaciers could reduce water availability in Asia (Chakraborty & Newton, 2011; Shrestha et al 2011) and in the foothills of the Andes with implications for tourism, hydropower and agriculture (Chevallier et al 2011). Although during the melting period flows would increase, the risk of dangerous floods would increase as well. Regarding social systems, studies continue to find that projected climate change threatens the hunting and food sharing culture of the Inuit population (Crowley et al 2011).

19.6.3.2. Extreme Events

[to be updated based on WGI SOD]

Extreme weather events (e.g., heat waves, intense precipitation, tropical cyclones) are physical impacts that can pose key risks to societies that are exposed and vulnerable. The IPCC Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX, IPCC 2012) provides a comprehensive assessment indicating modest changes in frequency of occurrence, intensity, and extent of these risks since AR4 (IPCC 2012 Ch. 3), while at the same time clarifying the factors which contribute to vulnerability, and means to address the latter. Furthermore, SREX based its conclusions on new literature since AR4. Based on this report, we assess that the risk from extreme events has not changed significantly since AR4.

19.6.3.3. Distribution of Impacts

The potential distribution of impacts is a category of climate change consequences that includes key risks to particular societies and social-ecological systems that may be disproportionately affected due to unequal distribution of vulnerability and of physical climate impacts. AR4 concluded that there is high confidence that low-latitude, less-developed areas are generally at greatest risk and found that, because vulnerability to climate change is also highly variable within countries, some population groups in developed countries are also highly vulnerable even to a warming of less than 2°C (Schneider et al., 2007). These conclusions remain valid and are now supported by more impact studies that explicitly consider differences in socio-economic conditions across regions or populations that affect vulnerability.

Economic (including insured) disaster losses associated with weather, climate, and geophysical events are higher in developed countries, while fatality rates and economic losses expressed as a proportion of GDP are higher in developing countries (SREX-SPM), a finding that emphasizes the importance of exposure to the vulnerability of human systems.

There is new evidence for a risk of widespread deterioration of regional food security in the 21st century with warming levels of 1.5-2°C, due to new assessments of the role of CO2 fertilization (Hare et al. 2011) and of pests and tropospheric ozone (Reilly et al 2007; Avnery et al., 2011; Sutherst et al., 2011). If partial Himalayan glacier melt eventually reduces runoff, water availability would be reduced in an area of Asia that produces 25% of the world's cereals (Chakraborty & Newton, 2011, Shrestha et al 2011).

Agricultural yields are projected to increase in some regions and decrease in others in ways that may be difficult to compensate for through international trade (Battisti & Naylor, 2009; Penny et al, 2010). Areas that are particularly vulnerable include those surrounding the Namib and the Mediterranean due to projected desertification (Brauch 2006); the southern half of Russia, due to projected drought increase (Dronin & Kirilemko 2011); Australia, where ongoing water stress and agricultural losses are projected to increase under further climate change (Risbey 2011, Steffen et al 2011); and North Africa where current climate variability already produces severe impacts due to long droughts (Sissoko et al 2010); and some parts of sub-Saharan Africa where large losses in agricultural production could occur (Muller et al 2011).,

Finally, since AR4 there has been increased understanding confirming areas where natural ecosystems are particularly vulnerable to climate change, for example the Wet Tropics of Queensland, Australia (a World Heritage Area) and in southwest Australia, one of 25 identified global hotspots of high endemism (Hughes 2011), where even 1C of warming is projected to have negative effects.

19.6.3.4. Aggregate Impacts

The RFC pertaining to aggregate impacts includes risks to society or ecosystems that are aggregated globally into a single metric, such as monetary damages, lives affected, or lives lost, although most aggregations in the literature are carried out in monetary terms. Estimates of the aggregate, economy-wide risks of climate change have increased since AR4 and their uncertainty has been more frequently acknowledged. Studies at the sectoral level have been refined with new data and models, and have assessed new sectors.

For example, impacts on the health sector have not previously included the direct effects of heat and humidity on productivity. New studies indicate that there is *high confidence* that these effects will have a negative impact on global economic output and human welfare (Dell et al., 2009; Hsiang, 2010). Heat- and humidity-related declines in available workdays of up to 19% by the middle of the century have been projected in some regions (Kjellstrom et al., 2009; SRES A2 scenario). When considering effects of disease as well, labor productivity losses are projected to lead to a global output loss of ~1.8% with ~3°C of warming above pre-Industrial levels and ~4.6% with ~6°C of warming (Roson and Mensbrugghe, 2010). For more extreme levels of warming, beginning at about 8°C above pre-Industrial temperatures, some areas will become physiologically uninhabitable for humans for portions of the year in the absence of adaptive measures such as fail-safe air conditioning (Sherwood and Huber, 2010).

Assessments of risks to coastal populations due to sea level rise have advanced through the application of more geographically detailed coastal databases in models that include adaptation options (Hinkel and Klein, 2009). One global study found that without investment in coastal protection, 50 cm of globally uniform sea level rise would displace about 70 million people by 2100, while 2 m of globally uniform sea level rise would displace about 187 million people; the costs of protection are estimated at $25 billion/year and $270 billion/year [in 1995 USD], respectively (Nicholls et al., 2011, SRES A1B scenario). Similarly, an assessment of risks from tropical cyclones that depend on both climate and socio-economic conditions projected an increase in cyclone damages globally of $14-US$80 billion/year [in presumptive 2011 USD] by 2100 (0.01% of global GDP), on top of baseline damages of $56 billion/yr (Mendelsohn et al., 2012; SRES A1B scenario).

Assessments of economy-wide consequences of climate change report results either as total damages or as marginal damages, the latter represented by the social cost of carbon. Estimates of global aggregate impacts from integrated assessment models (Figure 19-5) have increased modestly since AR4 (Nordhaus, 2008, 2011; Interagency Working Group on the Social Cost of Carbon, United States Government, 2010; Roson and Mensbrugghe, 2010; Ackerman et al., 2011; Hope, 2011; Bosello et al., 2012). Consistent with AR4, there remains *high confidence* that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts (Yohe and Tirpak, 2008; Warren, 2011; Kopp and Mignone, 2012). There is *very high confidence* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. In some locations and amongst some groups of people with high exposure and high vulnerability, net costs per capita will be significantly larger than the global average (Anthoff et al., 2009; Nordhaus, 2011; Warren, 2011). In addition, there remains a *low level of agreement* between IAMs in the sectoral calibrations used to estimate global aggregate damages (Figure 19-6).

[INSERT FIGURE 19-5 HERE
Figure 19-5: Representative global damage estimates, shown as a % of global output as a function of temperature. FUND: (Interagency Working Group on the Social Cost of Carbon, United States Government, 2010). DICE: (Nordhaus, 2008, 2011). PAGE: (Hope, 2011). CRED: (Ackerman et al., 2011). ENVISAGE: (Roson and Mensbrugghe, 2010). ICES: (Bosello et al., 2012). Note that, of models shown, only DICE and CRED (the damage function of which is recalibrated from that of DICE based on (Hanemann, 2008)) and PAGE attempt to include uncertain catastrophic damages, and only ENVISAGE includes labor productivity lost due to heat/humidity. For comparison, DICE 2007 damages are also shown considering only non-catastrophic impacts.]

[INSERT FIGURE 19-6 HERE
Figure 19-6: Breakdown of damages at 2.5°C above pre-industrial by sector in DICE 2007 (Nordhaus, 2007), FUND 2.7 (Warren et al., 2006) and ENVISAGE (Roson and Mensbrugghe, 2010), reflecting a low level of agreement among the integrated assessment models used to estimate global aggregate damages. Modified from (Kopp and Mignone, 2012). Note that the DICE calibration does not include damages due to changes in water resources as distinct from temperature impacts on agriculture and forestry, and FUND and ENVISAGE do not include expected catastrophic damages. Representations of changes in energy demand, coastal/sea level impacts, health and labor productivity impacts, and impacts on settlements, ecosystem and tourism are included in all three models.]

Alternative measures of global aggregate damages have been proposed based upon historical and geographic relationships between temperature and economic growth. *Limited evidence* suggests that higher temperatures decrease growth rates in low-income countries by ~1.3%-2.5%/year per 1°C (Dell et al., 2009, 2012; Hsiang, 2010). Consistent with studies on the relationship between temperature and labor productivity, higher temperatures appear to reduce both agricultural and industrial output in low-income countries; they also appear to increase political instability, which will also contribute to decreased economic growth (Dell et al., 2012). Modest changes in economic growth rate can accumulate to large changes in output over time, although the studies conducted to date do not address the possibility of long-term adaptation.

The aggregate damage estimates in IAMs exclude a number of potentially significant factors, including the consequences of earth system tipping points (Lenton, in rev; Kopp and Mignone, 2012), intersectoral and interregional interactions (see section 19.3; Warren, 2011) (Bosello et al., 2012) , and imperfectly substitutable environmental goods, which reflects the fact that impacts on (for example) ecosystems cannot be replaced 1-for-1 by an increased consumption of material goods (Sterner and Persson, 2008; Weitzman, 2010; Kopp et al., 2012). Additionally, studies lack evidence for extrapolating damages from temperature increases at which impact studies have been carried out to higher temperatures (Ackerman et al., 2010; Weitzman, 2010; Ackerman and Stanton, 2012; Kopp et al., 2012). There is *very high confidence* that the exclusion of these factors leads to an underestimate of global aggregate impacts. In addition, adaptation is treated differently across modeling studies (Patt et al., 2010) (Hope, 2006; de Bruin et al., 2009; Bosello et al., 2010) (Bosello et al., 2012) and affects aggregate damage estimates in ambiguous ways.

The social cost of carbon (SCC) is an alternative index of aggregate damages that measures the consequences of a marginal increase in carbon dioxide emissions in a given year, aggregated across space, time, and probability (e.g., Newbold et al., 2010; Nordhaus, 2011; Tol, 2011; Kopp and Mignone, 2012). Central estimates of the SCC have increased since AR4. For example, the mean value of the 217 post-TAR social cost of carbon estimates incorporated into the meta-analysis of Tol (2011), which are produced predominantly by the FUND model, is \$31/tCO$_2$. By comparison, the meta-analysis of (Tol, 2005), cited in AR4, found a mean of \$25/tCO$_2$.

The uncertainty in SCC estimates has also increased since AR4. The post-TAR estimates in Tol (2011) have a 95th percentile value of \$112/tCO2, compared to \$95/tCO2 in Tol (2005). Moreover, additional studies not included in this meta-analysis (Hope, 2011; Ackerman and Stanton, 2012; Kopp et al., 2012) further reduce the level of agreement and expand the uncertainty range (Table 19-4); including these results suggests *high confidence* that the SCC is between \$0 and \$1,000/tCO$_2$. Uncertainty in SCC estimates is high due to under-representation of uncertainty in socio-economic scenarios, under-representation in some models of uncertainty in climate/carbon cycle, fidelity issues regarding the reduced-form climate/carbon cycle models used in the principal IAMs (Warren et al., 2010; Hof et al., 2011; Marten, 2011; van Vuuren et al., 2011), and low level of agreement regarding the appropriate framework for aggregating impacts over time (discounting), regions (equity weighing), and states of the world (risk aversion). The uncertainty range has increased since AR4 due to new estimates employing different damage functions and discounting and risk aversion assumptions (Table 19-4). Quantitative analyses have shown that SCC estimates can vary by ~2x depending on assumptions about future demographic conditions (Interagency Working Group on the Social Cost of Carbon, United States Government, 2010), ~3x due to the incorporation of uncertainty (Kopp et al., 2012), and ~4x due to differences in discounting (Tol, 2011) or alternative damage functions (Ackerman and Stanton, 2012). A further source of uncertainty is whether and how the possibility of catastrophic damages is accounted for (Weitzman, 2009; Dietz, 2010; Nordhaus, 2011b), which requires bounding potential losses with a parameter akin to the value of a statistical life (representing, essentially, willingness to pay to avoid human extinction) (Dietz, 2010; Kopp et al., 2012).

[INSERT TABLE 19-4 HERE
Table 19-4: Estimates of the Social Cost of Carbon. From AR4 WG2 20.6.1, with new values from DICE: Nordhaus, in rev.; FUND: Anthoff et al., 2009; PAGE: Hope, in rev.; CRED: Ackerman & Stanton, in rev.; matDICE: Kopp et al., in rev.]

19.6.3.5. Large-Scale Singular Events: Physical, Ecological, and Social System Thresholds and Irreversible Change

[to be updated based on WGI SOD]

Large-scale singular events (sometimes called “tipping points”) are abrupt and drastic changes in physical, ecological, or social systems in response to smooth variations in driving forces (Smith et al., 2001; Smith et al 2009). They pose key risks because of the potential magnitude of the consequences, the rate at which they would occur, and the limited ability of society to cope with them.

Regarding singular events in physical systems, AR4 expressed medium confidence that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic Ice Sheet (WAIS), would occur over a period of time ranging from centuries to millennia for a global average temperature increase of 1-4°C (relative to 1990-2000), causing a contribution to sea-level rise of 4-6 m or more (Schneider et al., 2007). Recent studies are consistent with these judgments but provide a more nuanced view. At the current time, the two ice sheets are making approximately equal contributions to sea level rise [CK and CITE WGI]. Recent studies (McKay et al 2011, Kopp et al 2009) suggest a comparable contribution from the two ice sheets during the Last Interglacial, which provides a partial analog for 21st century warming. A recent study (Robinson et al 2012) lowered the threshold for near-complete melting of the Greenland ice sheet to 0.8-3.2C above preindustrial temperatures from 1.9-5.1C global warming in

AR4. Expert elicitations (Kriegler 2009) and other approaches (Good et al 2011) have led to assessments that a complete melting of Greenland is *unlikely* below 2C and *likely* above 4C compared to current temperatures. The question of whether the melting of Greenland is irreversible remains contested (Ridley et al 2010, Lunt et al 2004; Robinson et al 2012). A threshold for the disintegration of WAIS remains difficult to identify due to shortcomings in modeling the dynamical component of ice loss. Extreme exposure and vulnerability to the magnitude of sea level rise associated with loss of a significant fraction of either ice sheet is found worldwide (Nichols and Tol 2006).

There is also additional evidence regarding singular events in other physical systems. Feedback processes in the earth system cause accelerated emissions from wetlands, terrestrial permafrost and ocean hydrates but temperature sensitivity of these processes is not known and progress in determining this has been slow. However, the risk of a substantial carbon release from these processes increases with warming. Early model results indicate a modest additional warming, on the order of several percent (O'Connor et al 2010, Archer et al 2009, Zhang et al 2009). On the other hand, release of methane from permafrost may be abrupt. AR4 stated that Arctic summer sea ice disappears almost entirely in some projections by the end of the century (AR4 WGI 10.3), but new work constraining models with observations show that this could occur well before the end of the century (Wang and Overland 2009, Boe et al 2009). Whether or not the physical process is reversible, effects of ice loss on biodiversity may not be. Large uncertainties remain in estimating the probability of a shutdown of the Atlantic meridional circulation. One expert elicitation finds the chance of a shutdown to be between 0 and 60% for global average warming between 2-4C, and between 5 and 95% for 4-8C of warming (Kriegler et al 2009). Recent observational evidence confirms the susceptibility of the Amazon to drought and fire (Adams et al 2009), and recent improvements to models provide increased confidence in the existence of a tipping point in the Amazon (Lapola et al 2009, Jones et al 2009, Malhi et al 2009). One study proposed a 2°C limit to protect the Amazon from commitment to such a transformation (Phillips et al 2009).

Risks to biological systems include species extinction (see 19.6.3.1), which are sometimes classified as large-scale singular events. Such tipping points will occur in different ecosystems with different levels of warming (Warren et al 2010), and there is still uncertainty over when such points might be crossed.

19.6.3.6. Variations in RFCs across Socio-Economic Pathways

The determination of key risks as reflected in the Reasons for Concern (RFCs) has not previously been distinguished across alternative development pathways. In the TAR, RFCs took only autonomous adaptation into account (Smith et al., 2009). An update based on literature assessed in AR4 concluded that the RFCs reflect more steeply increasing risk with global average temperature change in each category (Smith et al., 2009; Schneider et al., 2007, AR4 WG2 Ch. 19), but this conclusion was not based on a change in the assessment of future development pathways but rather on evidence of some impacts already becoming apparent, higher likelihoods of some biophysical impacts, and better identification of currently vulnerable populations.

However, the RFCs represent risks that are determined by both the physical impacts of climate change and the vulnerability of social and ecological systems to climate change stresses. For some RFCs, this representation is explicit. For example, the aggregate impacts of climate change depend on both the physical climate change impacts and future socio-economic conditions (see Figure 19-7). In other cases ability to adapt, or lack thereof, is implicit, as in the category of large-scale singular events: these impacts are considered key based on an assumption that it would be difficult to adapt to such impacts for a wide range of socio-economic conditions.

[INSERT FIGURE 19-7 HERE
Figure 19-7: Illustration of the dependence of risk associated with the RFC related to aggregate impacts (section 19.6.3.4) on the level of climate change and vulnerability of society. For comparison, the representation from Smith et al. (2009) is shown, which does not explicitly take vulnerability into account. It is assumed here to be based implicitly on a medium level of future vulnerability. If future socio-economic conditions lead to more vulnerable societies, the aggregate impact risks associated with a given level of climate change would be higher. If future conditions lead to less vulnerable societies, risks for a given level of climate change would be lower. This figure is

schematic; the specific degree of risk associated with particular levels of climate change has not been based on a literature assessment.]

19.7. Assessment of Response Strategies to Manage these Risks

The management of key and emerging risks of climate change can include mitigation that reduces the likelihood of physical impacts and adaptation that reduces the vulnerability of society and ecosystems to those impacts. This section therefore assesses relationships between mitigation, adaptation, and the residual impacts that generate key and emerging risks. It also considers limits to both mitigation and adaptation responses, because understanding where these limits lie is critical to anticipating risks that may be unavoidable. Potential threshold impacts on physical, ecological, and social systems (19.6.3.5) are particularly important elements of key risks, and the section therefore assesses response strategies aimed at avoiding or adapting to them. Finally, this section considers governance responses, which are particularly important elements of adaptation and mitigation strategies aimed at managing key and emerging risks.

19.7.1. Relationship between Adaptation Efforts, Mitigation Efforts, and Residual Impacts

Response strategies to climate change can be thought of in broad terms as mixes of mitigation and adaptation that together will imply some degree of residual impacts. Evaluating the potential mixes of mitigation, adaptation, and impacts is an important task, since key risks and vulnerabilities for social-ecological systems will vary along with these mixes, as will the nature of Reasons for Concern (19.6). The task is made complicated by the fact that it requires joint consideration of alternative outcomes for both climate change and socio-economic development. Such an approach is complicated because socio-economic development pathways will influence future emissions, land use change, and therefore climate change (WG3, Ch. 5), and in turn climate change will influence development pathways through feedbacks on social and economic systems, including policy responses (AR5 WGII Ch. 2, Ch. 20).

One perspective on these relationships is provided by studies of the benefits of mitigation, i.e., the impacts avoided by mitigation, which sometimes also account for adaptation. Avoided impacts vary significantly across regions due to (a) differing levels of regional (as opposed to global) climate change, (b) differing numbers of people and levels of resources at risk in different regions (e.g. presence of unique ecosystems or the size of the human population exposed to impacts), and (c) differing sensitivities and adaptive capacities of humans, species or ecosystems in different regions. Similarly, residual impacts will differ between sectors due to (a) different levels of sensitivity and (b) differing levels of adaptive capacity. They will also differ over time depending on which aspect of the physical climate system is driving them. Benefits accrue most rapidly for impacts associated with ocean acidification, less rapidly for those associated with change in temperature and/or precipitation, and least rapidly for impacts associated with sea level rise such as coastal flooding, loss of mangroves and coastal wetlands. Sea level rise responds very slowly to mitigation efforts so that mitigation can reduce the rate of sea level rise but under most emissions scenarios, cannot halt it altogether (Meehl et al 2012). Global temperature can be stabilized as a result of mitigation efforts, but even if anthropogenic CO2 emissions were reduced to zero, global average temperature would not decline significantly from its peak over a century timescale (Solomon et al., 2011; Matthews and Caldeira, 2008). Ocean acidification responds more quickly to changes in emissions of CO2 than does global temperature, with the rise in pH ceasing several decades after stringent emission reductions begin (Bernie et al. 2010).

Figure 19-8 gives an example of regional and sectoral variation within a harmonized analysis on a global scale of the avoided impacts of climate change resulting from efforts to implement stringent mitigation (Arnell et al, 2012). The figure shows the impacts avoided by reducing greenhouse gas emissions from a SRES A1B scenario to one in which global greenhouse gas emissions peak in either 2016 or 2030 and are reduced thereafter at 5% annually. The impacts avoided increase over time and by the 2080s range from 20-70% across sectors. This study reported large benefits in terms of avoided biodiversity impacts, which are confirmed by a more comprehensive independent study estimating that 40-60% of the projected loss in species range can be avoided (Warren et al, 2012). Results from both studies show that fewer impacts can be avoided when global emissions do not peak until 2030.

[INSERT FIGURE 19-8 HERE
Figure 19-8: Climate change impacts avoided by two different mitigation scenarios compared to a no-mitigation case (SRES A1B scenario). Since increases and decreases in water stress, flood risks and crop suitability are not co-located and affect different regions, these effects are not combined. From Arnell et al 2012.]

A limitation of this study, and in the literature more broadly, is the uneven treatment of adaptation. In some sectors adaptation was not included. In contrast, the assessment of sea level rise impacts considered a range of adaptation policies, showing that adaptation can greatly reduce the residual impacts (Nicholls et al 2011).

Other studies have also quantified the benefits of mitigation. Mitigation reduces by 80-95% the people additionally at risk of hunger in 2080 in the SRES A2 scenario (mostly in Africa), corresponding to a global saving of an estimated 23-34 billion US$ in terms of agricultural output (Tubiello & Fischer, 2007). Benefits varied regionally and were negative in some cases, for example in developed countries due to a positive, though uncertain, effect of CO2 fertilisation. Mitigation can also reduce overall potential welfare losses in the EU from 0.4-1% to 0.2-0.3% (Ciscar et al., 2011), with losses in the agricultural sector changing to gains, and the numbers of additional people affected by fluvial flooding decreasing from 318-396,000 annually to 251-276,000 annually.

Mitigation also produces benefits by reducing the rate of temperature increase, allowing more time for adaptation. A study of biodiversity impacts found that stringent mitigation could increase by 3 to 4 decades the time available for adaptation (Warren, 2012).

19.7.2. Limitations of Response Strategies

Key risks, impacts, and vulnerabilities to which societies and ecosystems may be subject will depend in large part on the mix of mitigation and adaptation measures undertaken. However, mitigation and adaptation possibilities are not unlimited, implying that some degree of residual damages will be unavoidable.

19.7.2.1. Limits to Mitigation

Assessment of maximum feasible mitigation (or lowest feasible emissions pathways) must account for the fact that feasibility is a subjective concept encompassing technological, economic, political, and social dimensions (Hare et al., 2010, UNEP Ch 2). Most mitigation studies have focused on technical feasibility, for example demonstrating that it is possible to reduce emissions enough to have at least a 50% chance of limiting warming to less than 2 C relative to pre-industrial (Edenhofer et al., 2010; Hare et al., 2010; den Elzen and van Vuuren, 2007; O'Neill et al., 2010; Clarke et al., 2009). Such scenarios lead to pathways in which global emissions peak within the next 1-2 decades and decline to 50-80% below 1990 levels by 2050, and in some cases exhibit negative emissions before the end of the century. In contrast, no model-based scenarios in the literature demonstrate the feasibility of limiting warming to a maximum of 1.5 C with at least 50% likelihood (UNEP, 2010; Ranger et al., 2012).

However, most studies of technical feasibility include a number of idealized assumptions, including availability of a wide range of mitigation technologies such as large scale renewable energy, carbon capture and storage, and large scale biomass energy. Most also assume universal participation in mitigation efforts beginning immediately, economically optimal reductions (i.e., reductions are made wherever they are cheapest), and no constraints on policy implementation. Any deviation from these idealized assumptions can significantly limit feasible mitigation reductions (Knopf et al., 2010). For example, delayed participation in reductions by non-OECD countries made concentration limits such as 450 ppmm CO2eq (roughly consistent with a 50% chance of remaining below 2C relative to pre-industrial), and in some cases even 550 ppm CO2eq, unachievable in some models unless temporary overshoot of these targets were allowed (Clarke et al., 2009), but not in others (Waldhoff 2011). Technology limits, such as unavailability of CCS or limited expansion of renewables or biomass makes stabilization at 450 ppm CO2eq unachievable in some models (Krey and Riahi, 2009). Costs may also become unacceptably high; for example, if low carbon power plants and other infrastructure were limited to new installations (as opposed to replacement of existing stock), the maximum emissions reduction rate would be limited to about 3%/yr (Davis et al., 2010). Similarly, if the political will to implement coordinated mitigation policies within or across a large number of countries is limited, peak emissions and subsequent reductions would be delayed (Webster, 2010).

These considerations have led some analysts to doubt the plausibility of limiting warming to 2 C (Tol, 2009; Anderson and Bows, 2008, 2011). "Emergency mitigation" options have also been considered that would go beyond the measures considered in most mitigation analyses (van Vuuren and Stehfest, 2009; Swart and Marinova, 2010). These include drastic emissions reductions achieved through limits on energy consumption (Anderson and Bows, 2011) or geoengineering through management of the earth's radiation budget (19.5.4; WGI Ch. 6, 7).

19.7.2.2. Limits to Adaptation

Chapter 16.2 and 16.5 provide a thorough assessment of the literature on limits to adaptation. Discussions are beginning on the nature of such limits, e.g. in terms of different dimensions of the limits of adaptation, including financial or economic limits to adapt, but also social and political or cognitive limits of adaptation are emerging issues. Furthermore, limits of adaptation are also recognized in terms of specific geographies, for example small island developing states and their limited ability to adapt to increasing impacts of sea level rise, the limits of adaptation of urban agglomerations in low-laying coastal zones (see e.g. Birkmann 2010b), or in relation to loss of water supplies as a result of glacier retreat (Orlove 2009).

There is new literature on the limits to adaptation from the perspective of distinct dimensions such as physical limits, or financial or social constraints (Adger 2009), which are pertinent to several key vulnerabilities and Reasons for Concern. For example, with regard to the risk of extreme weather events (Birkmann 2010a), new findings on physical limits may be of particular importance. Global warming of 7C would exceed a human adaptability limit to climate change due to heat stress (Sherwood & Huber 2011) by creating small zones where human metabolic heat dissipation would be impossible, and hence where lives would become dependent on air conditioning, and persons could not go outside. A global warming of 11-12C was projected to expose most of the human population to this level of risk. Since these estimates were based on extreme assumptions that the ‘people’ considered were doing all that they could to stay cool, by being dowsed with water in high winds and not working, a much larger fraction of the population could be at risk of life-threatening heat stress at lower, more realistic levels of global warming (see 19.3.10 and 19.6.1).

19.7.2.2.1. General considerations on key vulnerabilities and limits to adaptation

Intrinsic to any definition of “*dangerous anthropogenic interference with the climate system*” (UNFCCC, 1992, art 2) are assumptions about the capacity of natural systems, groups and societies to adapt to climatic change. The UNFCCC refers specifically to adaptation of ecosystems, threats to food production and the sustainability of economic development. There is evidence that while there are opportunities to adapt to climate change impacts in all natural and human systems, those opportunities are not unlimited and that ‘residual damage’ following adaptation is *likely* to occur in many cases (Smit and Wandel 2006; Stern, 2007; de Bruin et al., 2009; Patt et al., 2009). It is the extent of these residual damages (following adaptation) that determine whether anthropogenic interference with the climate is considered dangerous. If residual risks and damages are acceptable, or do not threaten ecosystems, food production and economic development, then they would not be deemed dangerous, at least in the context of Article 2. Only when residual risks or damages are deemed unacceptable, or lead to undesired discontinuities in natural or human systems, will they be perceived as dangerous interference [see 16.2.1].

This argument can be extended to the analysis of ‘key vulnerabilities’ to climate change. A key vulnerability to a social or biophysical system becomes evident once unacceptable risks or damages are experienced, following adaptation. For this reason, the definition of key vulnerabilities would normally include an assessment of adaptation opportunities and of the limits of adaptation to the social or biophysical risks identified. While the importance of adaptation has been widely acknowledged in previous IPCC statements (Schneider et al., 2007, 19.2 and 19.4), relatively little detailed attention has been paid to the complex question of limits to adaptation. Instead the focus has remained on assessments of globally-significant impacts of climate change. So, the AR4 assessment projects 'productivity decreases for some cereals in low latitudes' and 'productivity increases for some cereals in mid/high latitudes' with global mean temperature increases of 1-3°C by 2100 (medium/low confidence) (Schneider et al., 2007, Table 19-1). But there is also an acknowledgement of the large potentials for adaptation in food production. Without some assessment of potential limits to adaptive capacity in agriculture – for instance, by pointing to evidence of slowing potential yield growth in key cereal crops (Fischer and Edmeades, 2010) – it may remain hard to judge the significance of these productivity changes for the vulnerability of global food supply.

Adaptation may fail to prevent residual damages due to climate change impacts for different reasons. First, there may be a lack of opportunity to adapt. For instance, along some coasts there are few plausible options to respond to sea-level rise of over a meter in a century (Tol at al., 2007; Nicholls et al., 2010), or as on some Torres Straits Islands, adaptation to rising seas through retreat may not be an option due to limited high land (Green et al, 2009). Second, there may be constraints on the deployment of available adaptation options or strategies. There is substantial evidence that a range of perceptual, economic and institutional factors determine whether or not organizations in the private or public sectors choose to adapt to reduce potential vulnerabilities to climate change impacts (Ivey et al., 2004; Naess et al., 2005; Moser et al., 2008; Storbjork, 2010; Farley et al., 2011; Berrang-Ford et al., 2011; Berkhout, 2012). Third, there may be biophysical, technical, economic or other limits to adaptation. For instance, there may be physiological limits to heat-tolerance of certain key crops, such as wheat and maize (IPCC, 2007, TS Fig TS.7). Likewise, there are technical limits to artificial snow-making in response to less reliable snow conditions for skiing (Scott and McBoyle, 2007; Hoffman et al., 2009), or there may be economic limits to the insurability of disaster risks [see Box 16-4].

The existing scientific literature on limits to adaptation does not present a mature set of definitions, nor a consistent conceptual framework. Nor is there a consistent treatment of adaptation limits in the literature on adaptation. A number of different meanings are described and this has worked to confuse an important scientific and policy debate. The IPCC AR4, for example, used the terms constraints, barriers, and limits interchangeably to describe a variety of impediments to adaptation (Adger et al., 2007), and a similar confounding of meanings is evident across the literature. In AR5 [16.2] an adaptation limit is defined as '*…a situation in which an actor's objectives and values can no longer be secured from unacceptable risks through adaptive action, or where biophysical change threatens a valued ecosystem service*.' A limit to adaptation means that either no adaptation options exist, or that an unacceptable measure of adaptive effort is required to secure social objectives and values, or for a biological system to survive intact in its current state. Social objectives include, for instance, standards of safety (e.g. 1 in 500 year levees) or safe drinking water supplies. Values include attributes such as social equity, cultural cohesion, and preservation of livelihood practices. Key attributes of biophysical systems might include reproductive success of keystone species, or the pattern of precipitation in a region.

This definition of adaptation limits as the point at which there are unacceptable risks to social objectives and valued ecosystem services, points to the moral core for the concept. Defining when and for whom risks to social or ecosystem values become unacceptable, leads the analysis on to complex ethical issues. There will be large social and cultural differences in the exposure and vulnerability to climate-related risks, and the extent to which they are felt to be acceptable or not (IPCC SREX, 2012). Complicating this picture further is the observation that social values are not universal and are not static (O'Brien and Wolf, 2010). And these may not be economic values, but intangible cultural, aesthetic or spiritual values. Berkes (2008: 163) documents that in Inuit culture the loss of sea ice in summer months leaves some people feeling 'lonely for the ice.' Whether the risk of such a loss would be seen as unacceptable remains a complicated question and raises ethical issues which remain unresolved. This discussion points to a finding that limits to adaptation will often be perceived and experienced by actors as normative and ethical, rather than technical and economic.

Predicting limits to social or ecological adaptation remains analytically difficult. This is partly because climate risk assessment is difficult, and partly because predictions about what is deemed an unacceptable risk may be difficult. Ecological limits are related to regime shifts at local, regional or ecosystem scales. Assessments of regime shifts need to take account of the complex interaction between climate and other non-climate factors and shocks which threaten an ecosystem's resilience. For instance, forest-savannah transitions are influenced by drought and the prevalence of fire, but are also linked to rates of agricultural conversion (Petersen, 2009). But the deeper question of whether such a transition is unacceptable will often be hard to answer *ex ante*.

19.7.3. Avoiding Thresholds, Irreversible Change, and Large-Scale Singularities in the Earth System

Section 19.3.6 highlighted the reasons for concern related to non-linear changes in the Earth system, thereby anthropogenic forcings might cause irreversible and potentially rapid transitions. In general, the risk of triggering these transitions increases with increasing anthropogenic climate forcings or climate change (Kriegler et al., 2009; Lenton et al., 2008; Levermann et al., 2012; Zickfeld et al, 2007). Mitigation of greenhouse gas emissions is projected to reduce the risks of triggering such transitions. Adaptation, where possible (see 19.7.2.2), could reduce their consequences, should they occur.

A number of studies have sought to identify levels of atmospheric greenhouse gas concentrations or global average temperature change that would limit the risks of triggering these transitions (e.g., Keller et al., 2008; Kriegler et al., 2009; Lenton et al., 2008, Zickfeld et al, 2007). It is important to distinguish between triggering and experiencing a threshold response because model simulations and expert assessments suggest that there can be substantial delays between the two (e.g., Lenton et al., 2008; Urban and Keller, 2010). The analysis of Lenton et al. (2008), for example, suggests that limiting global mean temperature increase to approximately 3 ºC above present values would considerably reduce the risks of triggering an Amazon rainforest dieback, a melting of the West Antarctic ice sheet (WAIS), a collapse of the thermohaline circulation, and disruptions of the Sahara/Sahel and West African monsoon and the El Niño-Southern Oscillation systems. However, staying below this temperature limit does not entirely eliminate the risks of triggering these events (cf. Hansen et al., 2008; Kriegler et al., 2009; Levermann et al., 2012; Robinson et al., 2012; Zickfeld et al, 2007; Zickfeld et al., 2010). In particular, evidence from the Last Interglacial suggests that 2 ºC may be a more appropriate indicator of high risk for disintegration of WAIS (McKay et al 2011, Kopp et al 2009). In addition, this 3 ºC temperature limit would, in the assessments of Lenton et al (2008) or Levermann et al (2012), still result in considerable risks of triggering threshold responses such as a disintegration of the Greenland Ice Sheet or a melting of the Arctic summer sea-ice. There is low confidence in the location of such temperature limits due to disagreements among different experts (e.g., Zickfeld et al, 2007, Kriegler et al., 2009). Estimates of such temperature limits can change over time (cf., Oppenheimer et al., 2008) and may be subject to overconfidence that can introduce a downward bias in risk estimates of low-probability events (Henrion and Fischhoff, 1986; Keller, 2012; McNeall et al., 2011; Morgan and Henrion, 1995). Other climate change metrics (e.g., rates of climate change, spatial patterns of emissions and land use change, and atmospheric carbon dioxide concentrations) can be important in the consideration of response strategies (Lenton, 2011a; McAlpine et al., 2010; Steffen et al., 2011).

Several analyses have performed risk- and decision-analyses for specific thresholds, with most studies focusing on a single potential threshold response: a persistent weakening or collapse of the thermohaline circulation / Atlantic meridional overturning circulation (THC/AMOC) (e.g., Bahn et al., 2011; Bruckner and Zickfeld, 2009; Keller et al., 2004; Keller et al., 2005; McInerney and Keller, 2008; McInerney et al., 2012; Urban and Keller, 2010; Zickfeld and Bruckner, 2008). The probability of experiencing a THC collapse in this century has been assessed as *very unlikely* (Alley et al, 2007). However, as expected from the considerable response time of the THC, the probability of triggering an eventual THC collapse within a certain time period (e.g., this century) can be substantially higher than the probability of experiencing it (Urban and Keller, 2010). A probabilistic analysis sampling a subset of the relevant uncertainties concluded that reducing the probability of a THC collapse within the next few centuries to one in ten requires emissions reductions of 60% relative to a business-as-usual strategy by 2050 (McInerney and Keller, 2008). Bruckner and Zickfeld (2009) show that, under their worst-case conditions, emissions mitigation would need to begin within the next two decades to avoid an eventual THC collapse (defined as overturning rate reduced by more than 50%). Threshold risk estimates and the risk-management strategies are sensitive to factors such as the representation of the uncertainties and the decision-making frameworks (cf. McInerney et al., 2012; Polasky et al., 2011; Zickfeld and Bruckner, 2008).

Another set of analyses has examined broader aspects of how the consideration of threshold events affects response strategies, particularly for mitigation. For example, the design of risk-management strategies could be informed by observation and projection systems that would provide an actionable early warning signal of an approaching threshold response. Learning about key uncertain parameters (e.g., climate sensitivity or economic damages associated with a threshold response) can have a considerable effect on risk-management strategies and can have a substantial economic value of information (Keller et al., 2004; Lorenz et al., 2012). However, there is low confidence in the feasibility and requirements for such systems due to the limited amount of studies that have, thus far, mostly analyzed highly simplified situations (e.g., Keller and McInerney, 2008; Keller et al., 2008; Keller et al., 2007; Lenton, 2011b, Lorenz et al., 2012). In some decision-analytic frameworks, knowing that a threshold has been crossed can lead to reductions in emissions mitigation efforts (Keller et al., 2004) and a shift of resources toward adaptation (Guillerminet and Tol, 2008) and/or geoengineering of the Earth’s climate system (Irvine et al., 2009; Lenton, 2011b; Swart and Marinova, 2010).

19.7.4. Avoiding Tipping Points in Social/Ecological Systems

Tipping points in socio-ecological systems are defined as thresholds beyond which impacts increase non-linearly to the detriment of both human and natural systems. They pose a particularly important risk because they can be initiated rapidly and, until recently, without warning, inducing a need for rapid response from human systems. Because human and ecological systems are linked by the services that ecosystems provide to society (Lubchenko & Petes, 2010, McLeod & Leslie 2009), tipping points may be crossed when either the ecosystem services are disrupted and/or the social/economic networks are disrupted (Renaud et al. 2010). Climate change provides a stress on these services and networks that increases the potential for tipping points to be crossed, although they may be crossed due to other types of stresses even in the absence of climate change. For example, in dryland ecosystems, overgrazing has caused grassland-to-desert transitions in a number of locations (Pimm 2009).

The crossing of tipping points due to climate change can be avoided by preserving ecosystem services through (i) limiting the level of climate change and/or (ii) removing concomitant stresses such as overgrazing, fishing, and pollution. Most of the literature currently focuses on strategy (ii), and there is limited information about the exact levels of climate change that specific coupled socio-economic systems can withstand. Examples of strategy (ii) include maintaining the resilience of coral reefs or pelagic cephalopod populations by the removal of stress from fishing (Andre et al 2010, Anthony et al 2011). Similarly, risks to seabird populations due to climate change impacts on fish (prey) populations could be lessened by reducing concomitant fishing stress (Cury et al., 2011). In some cases, it is possible to use management to reverse the crossing of a tipping point, for example by adding an appropriately chosen amount of sediment to a submerged salt marsh (Stagg & Mendelssohn 2010). However, strategy (ii) generally becomes ineffective once climate changes beyond a certain threshold that is not well known and varies across socio-ecological system. Furthermore, some systems may contain multiple thresholds (Renaud et al., 2010) that may be crossed as stresses increase.

Other literature focuses more generally on the need for managing both marine and terrestrial ecosystems for resilience (Allen et al 2012, Lubchenko & Petes 2010). A particular category of threshold, that of regime shifts in ecosystems, has received much attention, and it has been noted that such shifts can be reversible in systems with high biodiversity; that is, a high level of biodiversity increases ecosystems’ resilience and enables them to recover after crossing a tipping point (Brierley et al. 2009, Lubchenko & Petes, 2010). Regime shifts have already occurred in several marine food webs (Byrnes et al. 2007; Alheit et al. 2009, Green et al 2008) as a result of (observed) changes in sea surface temperature, changes in salinity due to change in runoff, and (separately) natural climate variability, showing how future climate change will analogously affect species composition and hence ecosystem functioning and potentially biogeochemical cycles. Removal of concomitant stress such as nutrient loading can reduce the chance of a regime shift (Jurgensone et al 2011). Appropriate ecosystem monitoring that looks for a slowing down in the recovery of systems from small changes (Nes & Scheffer 2007) can give warning that a system is a approaching a regime shift, allowing intervention of type (ii) above to be implemented (Brock & Carpenter, 2010; Cuttal & Jayaprakash, 2008). Indicators that could be used for such monitoring have been identified for the desertification process in the Mediterranean (Alados et al, 2011) and for landscape fire dynamics (Zinck et al. 2011, McKenzie & Kennedy 2012).

19.7.5. Governance and Adaptation Strategies

Climate change adaptation strategies at the national level as well as local and household-based response strategies are influenced and in part determined by different forms of governance. Governance, and in particular risk governance, aims to enhance the resilience and human security of societies or regions. Risk governance includes all actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information, including information about climate change, its physical impacts, and societal vulnerabilities, is gathered, analyzed and communicated and management decisions are taken (IRGC, 2005).

Studies regarding the effectiveness of early warning systems in enhancing coping and adaptation capacities for responding to climatic stressors and natural hazards underscore the importance of governance processes and frameworks (see e.g. Chang-Seng 2010). Governance failure (e.g. in fragile and failed states) often leads to a lack of human security networks and therefore reduces the capacity of a social system to cope, adapt, or recover, capacities which are crucial to effective response strategies for managing risks (UN/ISDR, 2005).

Differences in governance structures, procedures and culture can lead to different response strategies to manage risk. For example, legal frameworks and political-administrative systems significantly determine how governmental response strategies are designed and by which institutions they are implemented (Greiving and Fleischhauer, 2012). Different governance structure may also place more or less importance on the role of the state (Ernst, 2004), and the relation between the state and the population can affect the orientation of a risk-related legal framework (Young, 2010). Trust in governance can also be a central to the success of response strategies at managing risks, particularly communication strategies (Löfstedt, 2005), with distrust reducing the efficiency and effectiveness of management actions (Greiving et al., 2012).

The SREX report (IPCC 2012) notes that "Governance is broader than governmental actions.… governance can be understood as the structures of common governance arrangements and processes of steering and coordination – including markets, hierarchies, networks, and communities" and added that "formal and informal governance structures also determine vulnerability, since they influence power relations, risk perceptions, and constitute the context in which vulnerability, risk reduction, and adaptation are managed" (Cardona et al., SREX Chapter 2, 2012). Governance is critical in facilitating development and building adaptive capacity but the link between development, adaptation and disaster risk reduction with governance is complex (Lal et al. SREX Chapter 6, 2012). For example counties such as China and Vietnam that are considered to be under authoritarian political regimes with insecure property rights, and underdeveloped rule of law have however, managed to address poverty and reduce vulnerability among a million of their citizens (The Advisory Board for Irish Aid, 2008; Lal et al. SREX Chapter 6, 2012). This is in contrast to Africa where institutional capacity to coordinate, regulate and facilitate development is weak, and in addition the media, watch-dog organizations and systems of checks and balances are constrained, resulting in failed development, widespread poverty and low capacity to response to climate change risks (The Advisory Board for Irish Aid, 2008). In addition government's response to climate risks in terms of willingness to avoid crisis, tailor relief efforts to need, and appeal for aid in an area depends among others on the kind of political relationships that existed before the crisis (Raleigh, 2010).

Literature on 'environmental security' argues that climate change would lead to political instability especially in poor and underdeveloped states such as those in Africa reducing further governance capacity to respond to risks and deepening vulnerability (Tor Benjaminsen, 2008). There is *likely* to be increased dependence on natural resources among conflict-torn societies and resource scarcity may lead to conflict (Brunnschweiler and Bulte, 2009). Conflicts in Darfur, Chad, Somalia, and Mali are usually cited as examples of cases of wars triggered by resource scarcity and distribution (Tor Benjaminsen, 2008). There is an emerging literature but no consensus yet on the role of climate change and weakened governance leading to conflict or outbreak of war (see 19.4.2.2). What is undisputable is that prospects for effective governance required to address climate change risks and disasters are greatly reduced during conflicts due to destruction of infrastructure and shelter, redirection of resources from social to military purposes, loss of skilled labour, lawlessness, and disruption of social networks. These contribute to resources scarcity, increased exposure and sensitive of communities to climate risks and other stresses (Hadmaer, SREX Chapter 4, 2012).

As a result, there is a potential for climate change to fuel pre-exiting tensions and inequalities that are linked for instance in Sub-Saharan Africa, to weak governing systems skewed towards patron–client political relationships resulting in disproportional government representation and marginalization of some groups (Sabates-Wheeler, 2008; Raleigh, 2010). Tor Benjaminsen (2008) noted that droughts of the 1970s and 1980s in northern Mali, had a role in the Tuareg rebellion but the original tension was driven by marginalization by state policies of modernization and sedentarization of nomadic pastoralists and poor governance resulting in embezzlement of drought relief funds. The vulnerability of Masai pastoralists to drought in Kenya is also a combination of inadequate state capacity and years of marginalization (Sabates-Wheeler et al. 2008; Raleigh, 2010).

Many developing countries are yet to build capable states that can deliver a comprehensive climate change risk response governance structure. Where ethno-political groups underlie the governing system, governments rarely exercise sovereignty across their full territories. This in addition to limited resources reduces equitable delivery of basic social services and capacity to respond effectively to climate change risks to all citizens (Raleigh, 2010; Osbahr et al., 2008). Uneven and disproportionate responses to risks within the same country have been witnessed in, among others, Mali, Niger and Kenya (Raleigh, 2010). In such cases influential social groups have environmental pressures mediated by government intervention in both pre- and post-disaster e.g. in terms of better roads, hospitals, relief aid, coping assistance while the marginalized have limited access to these services leading to "(i) increased risk of communal violence over access; (ii) heightened levels of distress migration to relief; and (iii) increased poverty and decreased coping strategies during periods of compounded disasters "Raleigh, 2010). Because they are a minor factor in the governing process, governments are not compelled to expend scarce public goods to these less influential communities. Raleigh (2010) suggested mapping zones of marginalization and extreme poverty as nuclei of potential conflict and increased vulnerability as climate change risks increases.

Weak governance, scarce resources resulting in widespread poverty drives rapid urbanization in developing countries resulting in the concentration of informal settlements in disaster risk areas that are lacking basic services e.g. housing, storm water drainage and sanitation. High flood-risk parts of certain districts of Saint Louis in Senegal dominated by minority groups and or lower-income groups are good example of such nucleus of vulnerability (Diagne, 2007; Murray et al., SREX, Chapter 9, 2012).

Climate change presents risks of a magnitude and kind outside of previous experience of many communities, but natural hazards and disasters are not new and all communities had well developed risk management governing systems that involve disaster prevention, prediction, early warning, mitigation and recovery built into indigenous knowledge and the livelihood systems (Mwaura, 2008; Osbahr et al., 2008). Poor interfacing of the indigenous livelihoods systems including its governing institutions with modern institutions undermined more locally adapted systems leading to overall weakened risk management governing systems at all levels i.e. from household through community to district and national level (Dube and Sekhwela, 2007 and 2008; Osbahr et al., 2008; Adger et al. 2009; Tor Benjaminsen, 2008). This is the case for much of African indigenous systems but is more pronounced for the politically and economically marginalized groups such as nomadic pastoralists in the Sahel and hunter gathers in the Kalahari in Southern Africa and other low income groups e.g. in urban areas(Tor Benjaminsen, 2008; Pansiri, 2008; Raleigh, 2010).

However, modern African states are not purely patrimonial but rather hybrid formations with strong bureaucratic and democratic features underpinned by formal bodies of law, political constitutions a development process that is guided by national development plans (NDP); for instance Botswana is currently on NDP10 (The Advisory Board for Irish Aid, 2008). There is a potential to strengthen governance structures for climate change adaptation and disaster management. The Mozambique government conducted a comprehensive vulnerability mapping exercise, and put measures in place to mainstream disaster risk reduction and climate change adaptation across its development policy through a cross-scale governance structure supported by a participatory decision-making processes. This has allowed community adaptation to be linked with NGOs, Government effort and to effectively utilize regional forecast outputs for early warning and monitoring to improve risk governance resulting in lower impacts of disasters compared to for e.g. the devastating floods of 2000 (Osbahr et al., 2008; Murray et al., SREX Chapter 9, 2012). Similarly in Asia, Bangladesh has through its history of large-scale disasters made significant improvements in Disaster Risk Reduction from tropical cyclones through a governing systems that includes policy makers, donors, NGOs, humanitarian organizations and local communities (Paul, 2009).

Frequently Asked Questions

FAQ 19.1: How do risks differ from impacts and vulnerabilities?

Impact, as used in this report, is the effect or damage to natural and human systems of physical events associated with climate change, for example the extent or cost of flooding due to an intense coastal storm. Risk is defined as the probability of a damaging event or series of events occurring times the impact or amount of damage that such event(s) would cause, measured in monetary value, number of human lives lost, number of species lost to extinction, or the value of other human, cultural, or monetized losses. In other words, risk refers to a situation where something of human value (including humans themselves) is at stake and where the outcome is uncertain. Vulnerability is the susceptibility of people, societies or natural ecosystems and species to damages due to such event(s). High vulnerability leads to high impact when a person, society, or ecosystem is exposed to damaging physical event(s). (chapter 2-ES, chapter 19.1)

FAQ 19.2: How can climate change at one location cause impacts at another, distant location?

Impacts of climate change are felt locally and directly where the events related to a changing climate occur. However, such impacts may cause responses on the part of humans, societies, and ecosystems and species which reverberate elsewhere and cause important indirect impacts at great distance from the initial climate impact. For example, a changing climate may lead to reduced crop productivity in some regions, reducing agricultural commodities supplied from that region and increasing demand for and price of the same or substitute crops grown in distant regions. In that case, the indirect impact is transmitted by price changes in the global commodities markets. In a second example, people may migrate in response to climate change, leading to potential for both positive and negative consequences at receiving regions that may be far removed from the point of origin of the migrants. (Chapter 19.3, 19.4)

FAQ 19.3: Does science provide an answer to the question of how much warming is excessive?

The question of how much warming is excessive is raised in Article 2 of the UN Framework Convention on Climate Change (UNFCCC). The criteria for determining what constitutes, in the words of Article 2, “dangerous interference with the climate system” are based both on science and human values. Science can determine, within a range of uncertainty, how much damage might done if tropical cyclones grow more intense or heat waves more frequent, for example. But comparing damages across communities, countries, or larger regions depends on how each political, social, or cultural entity values the losses. Comparing loss of property and loss of life is even more difficult and controversial, particularly when damage to future generations is involved. The purpose of this chapter is to highlight key risks and vulnerabilities that science has identified; however it is up to people and governments to determine how these potential impacts should be valued. For example, agreements reached by governments since 2009, meeting under the auspices of the UNFCCC, have recognized “the scientific view that the increase in global temperature should be below 2 degrees Celsius”. (Chapter 19.1, UNFCCC, Copenhagen Accord)

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Table 19-1: Emergent risks related to biofuel production as a mitigation strategy.

Issue number	Issue description	Nature of emergent risk	Reference
(i)Biofuel production	Potential for enhancement of greenhouse gas emissions	Does not contribute to mitigation	Wise et al 2009 Mellilo et al 2009 Khanna et al 2011
(ii) Policies targeting only fossil carbon	Competition for land reducing natural forest impacting on biodiversity	Benefits of mitigation for biodiversity offset by land use change	Wise et al 2009 Mellilo et al 2009 Lapola et al 2010 Fargione et al 2010
(iii) Food/fuel competition for land	Competition for land driving up food prices and impacting on numbers of people at risk of hunger	Benefits of mitigation to agriculture offset by land use change	Hertel et al. 2010, Searchinger et al. 2008
(iv) Biofuels production effects water resources	Competition for water impacting on biodiversity and food cropping	Benefits of mitigation for biodiversity and agriculture offset by water stress	Fargione et al 2010, Fingerman et al 2010
(v) Land conversion causes air pollution	Potential for increased production of tropospheric ozone	Benefits of mitigation for biodiversity and agriculture offset by damage caused by tropospheric ozone	Hewitt et al 2009, Cancado et al. 2006
(vi) Fertilizer application	Potential for increased emissions of N2O	Does not contribute to mitigation	Donner & Kucharik 2008, Searchinger et al. 2008, Fargione et al 2010
(vii) Land use change and local climate	Contributes to change in local climate caused by land use change generally	Benefits of mitigation to climate offset by disruption of local climate regime	Grossman & Clarke 2010
(viii) Invasive properties of biofuel crops	Potential to become an invasive species	Unintended consequences that damage agriculture and/or biodiversity	Barney & Ditomaso 2008, Council for Agricultural Science and Technology 2007, Raghu et al. 2006

NOTES:

(i) First-generation biofuel consumption has been projected to increase by up to 170-220% by 2020 and up to 250-620% by 2030 (IEA, 2009), with the larger numbers corresponding to the implementation of a limit of 450ppm for CO2 concentrations. Second generation biofuels are thought not to be commercially viable for large scale production until after 2020. Biofuels presently occupy about 2.2% of global cropland, whilst the area under cultivation itself is expanding at some 3.4 million ha/yr (FAO 2010) due to rising demand for food. Hence, such large projections for increase in biofuel production have profound implications for land use. If this biofuel induced land use change removes primary forest, the net contribution of the biofuel cropping towards climate change mitigation may be negative. The potential scope of the impact on a global scale is revealed in one study (Wise et al 2009) which considers a scenario leading to conversion of more than 40% of global land area to biofuel production by 2095.

(ii) Large scale conversion of natural forest induced by a carbon tax that does not include terrestrial carbon would have a severe impact on biodiversity (see section 19.4.x) through the destruction of most remaining natural ecosystems (Wise et al 2009). In Brazil, the resulting biofuel expansion is likely to impinge upon the Cerrado, the Amazon and the Atlantic rainforest all three of which have high biodiversity and high levels of endemism (Lapola et a 2010). Concessions of large areas for biofuel production have been made in the Brazilian Amazon, Papua New Guinea, and Madagascar, all of which are biodiversity hotspots (Koh et al. 2009). Biodiversity is reduced by about 60% in U.S. corn and soybean fields and by about 85% in Southeast Asian oil palm plantations compared to unconverted habitat (Fitzherbert et a 2008, Fletcher et al. 2010, Fargione 2010). The resultant loss of ecosystem services (Xref section above) would impact on human populations.

(iii)Displacement of agricultural land for biofuel crops would influence world food supply and prices (Hertel et al. 2010, Searchinger et al. 2008), as actually occurred during the food price crisis of 2007/2008 (Pimentel 2009), thus increasing risks of malnutrition. A new assessment of agricultural land availability projects that by 2050, substantial areas of agricultural land will be lost to urbanization, desertification, sea level rise and increasing salt water intrusion (Foresight 2011) which will act to increase competition between cropping for food and biofuels. Mellilo et al. (2009) project that up to twice as much carbon loss can occur as result of this indirect land use change, than from the direct land use change associated with biofuel production. Some biofuel feedstocks such as wastes, residues, cover crops, and forest thinnings (Tilman et al. 2009) are not in competition with cropland.

(iv) Demand for water use by biofuel cropping also has implications for the groundwater extraction issue discussed above, and hence can potentially reduce local water availability and quality. The water requirements of many biofuel crops are substantial (Fargione et al 2010, Fingerman et al 2010) and hence there would be potential for conflict with efforts to allocate water for domestic, industrial, agricultural and natural wetlands particularly where irrigation is required (find more refs).

(v) Where rainforest is converted to oil palm plantations, or where land is converted to sugarcane ethanol production, emissions of the precursors of tropospheric ozone increase (Hewitt et al 2009, Cancado et al. 2006).

(vi) Where biofuels displace nitrogen-fixing crops such as soybean, fertiliser application will increase, leading to increased N_2O emissions and nitrogen runoff into rivers and oceans (Donner & Kucharik 2008). At the same time, displacement of food crops, in combination with reduced yields due to climate change impacts, would encourage farmers to increase yields through application of larger amounts of fertiliser, particularly in countries where there is a supply shortfall (Deryng et al. 2011) which in turn increases greenhouse gas emissions.
Model estimates of 21st century land use project that at least 16% of the earth's surface would be converted for first-generation biofuel production, bringing the total area under cultivation from its current 12% to 28%. Such large increases in the cultivated area of the earth's surface would greatly exacerbate emissions of N_2O, enhancing warming (Searchinger et al 2008, Fargione 2010).

(vii) Land use change also has direct effects on local climate: for example, new urban developments caused an intensification and expansion of the area experiencing extreme temperatures, mainly increasing nighttime temperatures, by as much as 10 K. (Grossman & Clarke 2010).

(viii) Traits that make a plant a good candidate for biomass production also make it a potential invasive species (Barney & Ditomaso 2008, Council for Agricultural Science and Technology 2007, Raghu et al. 2006). This could result in damage to nearby ecosystems or agricultural systems.

Table 19-2: Key risks from large temperature rise.

Does not exist yet (To be provided with SOD)

Table 19-3: A selection of the physical impacts or other hazards, key vulnerabilities, key risks, and emergent risks based on the judgments of authors of various chapters of this report, utilizing the framework and systematization described in 19.2. The table indicates how these four categories are related as well as how they differ. The table is illustrative rather than comprehensive, aiming to show some examples of how of the framework may be applied across different themes and topics in the chapters. In addition to these examples, key risks may also arise from moderate vulnerability interacting with a very large physical impact.

Examples of Physical Impacts, Key Vulnerabilities, Key Risks and Emergent Risks based on the new systematization and classification (using preliminary input from other chapters)			
Physical impacts/hazards	**Key vulnerabilities**	**Key risks**	**Emergent risks**
Chapter 13 – Livelihood and Poverty			
Changing rainfall patterns (temporally and spatially)	High dependence on rain-fed agriculture. Little access to alternative modes of income.	Crop failure, food shortage, severe famine	May coincide with global food insecurity or periods of excessive global food prices which means that coping strategies (selling assets to buy food, relief operations) may not work. If widespread, adaptation mechanisms such as crop insurance (risk spreading) may collapse.
Soaring demand (and prices) of biofuels due to climate change policies.	Unclear and/or insecure land tenure arrangements.	Risk of dispossession of land due to "land grabbing" in developing countries.	Creation of large groups of landless farmers unable to support themselves. Social unrest due to disparities between intensive energy production and neglected food production.
Increasing frequency of extreme events (droughts, floods). For example if 1:20 year drought/flood becomes 1:5 year flood/drought.	Livelihoods subject to damage to their productive assets (if droughts – e.g. herds of livestock; if floods – dykes, fences, terraces).	Risk of the loss of livelihoods and harm due to the fact that the time for recovery between extreme events is progressively shorter. For example: pastoralists have to restock after a drought, which may take several years; in terraced agriculture there is a need to rebuild terraces after flood, which may take several years.	Collapse of coping strategies with risk of collapsing livelihoods. Adaptation mechanisms such as insurance fail due to increasing frequency of claims.
Chapter 19			
Warming and increased high temperature extremes	Urbanisation, aging of population and vital infrastructure	Increase in morbidity and infrastructure failure during heat waves	Increasing risk under all scenarios; long-term adaptive capacity poorly understood; interactive effects important
Warming and drying (degree of precipitation changes uncertain)	Limits to coping capacity to deal with reduced water availability; increasing exposure and demand due to population increase; conflicting demands for alternative water uses; socio-cultural constraints on some adaptation options	Risk of harm and loss due to livelihood degradation from systematic constraints on water resource use that lead to supply falling far below demand. In addition limited coping and adaptation options increase the risk of harm and loss.	Negative outcomes to sending and/or receiving regions due to migration of populations due to limits on agricultural productivity and livelihoods

Chapter 23			
Extreme weather events	Limited coping and adaptive capacity as well as high sensitivity of different sectors, e.g. transport, energy and health sector	Stress on multiple sectors can cause systemic risks due to interdependencies between the different sectors	Disproportionate intensification of risk due to increasing interdependencies
Climate change increases the spatial distribution and seasonality of pests and diseases	Vulnerability of plants and animals exposed to pests and diseases	Increases in crop losses and animal diseases or even fatalities of livestock	Increasing risks due to limited response options and various feedback processes in agriculture, e.g. in terms of the use of pesticides or antibiotics to protect plants and livestock
Extreme weather events and reduced water availability due to climate change	Low adaptive capacity of power supply systems, might lead to limited energy supply as well as higher supply costs during such extreme events and conditions	Increasing risk of power shortages due to limited energy supply, e.g. of nuclear power plants due to limited cooling water during heat stress	Continued underinvestment in adaptive energy systems might increase the risk of mismatches between limited energy supply during these events and increased demands, e.g. during a heat wave
Chapter 26			
Increases in frequency and/or intensity of extreme events, such as hurricanes, river and coastal floods, heat waves and droughts	Declining state of physical infrastructures in urban areas as well as increases in income disparities	Risk of serious harm and losses in urban areas, particularly in coastal environments due to enhanced vulnerabilities of social groups and physical systems combined with the increases of extreme weather events	Inability to reduce vulnerability in many areas results in increase in risk greater than change in physical hazard
Higher temperatures, decreases in runoff and lower soil moisture due to climate change	Increasing vulnerability of small landholders in agriculture	Increased losses and decreases in agricultural production increase food and job insecurity for small landholders and social groups in that region	Increasing risks of social instability and local economic disruption due to internal migration
Chapter 4			
Rising air, soil, and water temperature	Exceedence of eco-physiological climate tolerance limits of species, increased viability of alien organisms	Loss of native biodiversity, increase in alien organism dominance	Cascades of native species loss due to interdependencies
Rising air, soil, and water temperature	Epidemiology of temperature-sensitive vectors (insects	Novel or much more severe pest and pathogen outbreaks	Pest, drought and fire interactions lead to risk of large impacts
Change in seasonality of rain	Vulnerability of plants and ecosystem services, due to mismatch of plant life strategy to growth opportunities	Changes in plant functional type mix leading to biome change with respective risks	Fire-promoting grasses and summer fuels in winter-rainfall areas
Chapter 6			
Rising water temperature, increase of (thermal and haline) stratification, and marine acidification	Tolerance limits of endemic species surpassed, increased abundance of invasive organism, high vulnerability of warm water coral reefs and respective ecosystem services for coastal communities	Loss of endemic species, mixing of ecosystem types, increased dominance of invasive organisms, loss of coral cover and associated ecosystem with reduction of biodiversity	Enhancement of risk due to interactions, e.g., acidification and warming on calcareous organisms

Enhanced harmful algal blooms in coastal areas due to rising water temperature	Important ecosystems and valuable services already suffering multiple stresses	Enhanced frequency of dinoflagellate blooms and respective losses and degradations of coastal ecosystems and ecosystem services	Disproportionate enhancement of risk due to interactions of stresses
Chapter 22			
Increasing Temperature	Health of exposed nd vulnerable groups (increased exposure to heat, change in the transmission dynamics of vector-borne diseases)	Increase in disease burden – changes in the patterns of infection Decrease in outdoor worker productivity due to high temperature, increase in heat related morbidity and mortality	Emerging and re-emerging disease epidemics
Increasing Temperature	Vulnerability of aquatic systems and vulnerability of aquatic ecosystem services due to increased water temperatures	Loss of aquatic ecosystems and risks for people who might depend on these resources	
Extreme Events, e.g. floods and flash floods	Vulnerable and exposed urban areas, particularly in informal settlements	Increasing harm and losses due to water logging in terms of sudden volumes of rain	Due to water logging and contamination, compounded increase of the risk of epidemics
Chapter 24			
Significant reduction of glacier meltwater due to deglaciation	Limited adaptive capacity of ecosystems and social-ecological systems	Water scarcity and shifts in water flow regimes combined with the vulnerability of rural or urban livelihoods	Limited adaptive capacity and degradation of ecosystem services might lead to high risk of livelihood erosion
Chapter 25			
Warming and drying (uncertain degree of precipitation change)	Increasing exposure of human systems to these changes, increasing build-up of combustible material in CO_2-enriched environment	Increased damages to ecosystems and settlements and risks to human life from wildfires	
Warming and increased temperature high extremes	Urbanisation, aging of population and vital infrastructure	Increase in morbidity and infrastructure failure during heat waves	Large increase in risk from interactive stresses and vulnerability
Potential for sea level rise exceeding 1m	Long lifetime of coastal infrastructure, concentration and further expansion of coastal population and assets; conflicting priorities and time preferences constraining adaptation options; limited scope for managed retreat in highly developed areas	Widespread damages to coastal infrastructure and low-lying ecosystems	Interactions of large sea level rise with multiple stresses

Table 19-4: Estimates of the Social Cost of Carbon. From AR4 WG2 20.6.1, with new values from DICE: Nordhaus, in rev.; FUND: Anthoff et al., 2009; PAGE: Hope, in rev.; CRED: Ackerman & Stanton, in rev.; matDICE: Kopp et al., in rev.

Date of estimate / $/tCO$_2$	**1990**	**1995**	**2000**	**2005**	**2012**
DICE/RICE	$3	$2	$2		$12
FUND			$2 to $6	-$4 to $30	$0 to $63
PAGE		$3 to $16		$1 to $14	$10 to $270
CRED					$28 to $900
matDICE					$30 to $1000

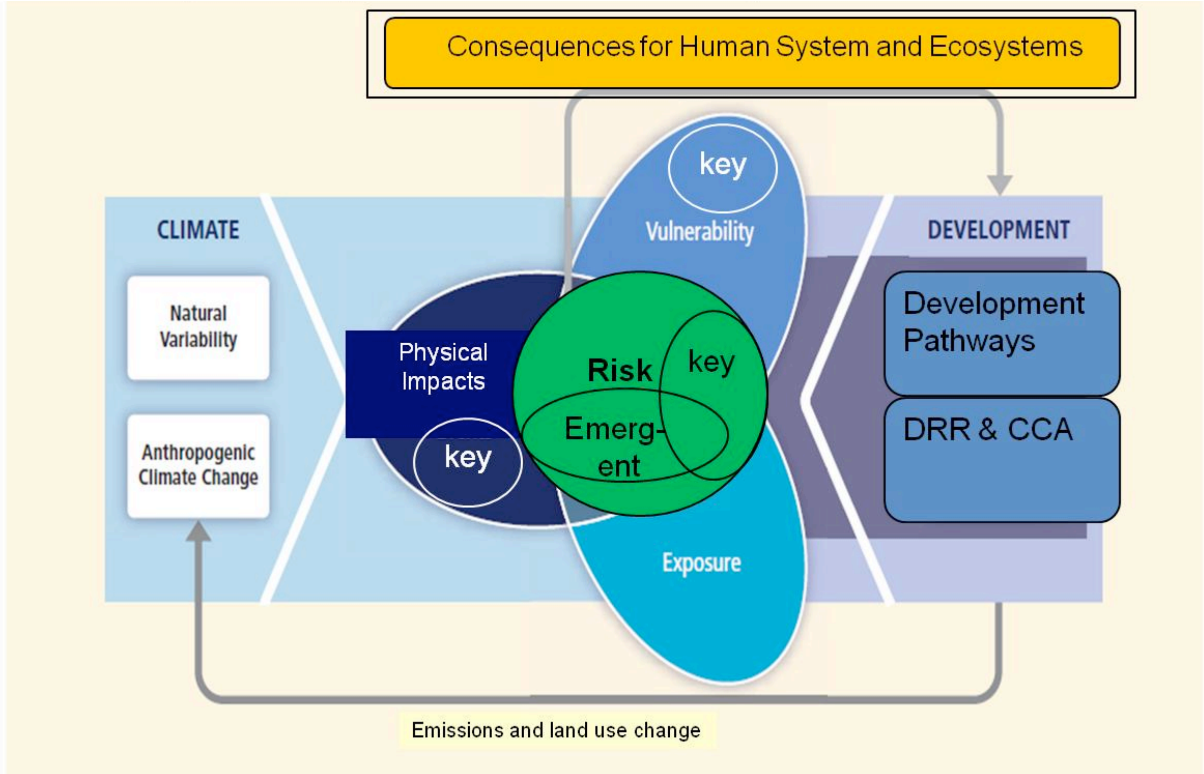

Figure19-1: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. The figure visualizes the different terms and concepts discussed in this chapter. It underscores that risks are a product of a complex interaction between physical impacts due to climate change and climate variability on the one hand and the vulnerability of a society or a social-ecological system and its exposure to climate-related hazards on the other. DRR means disaster risk reduction and CAA indicates climate change adaptation. The definition and use of “key” are indicated in Box 19-2 and the glossary. Vulnerability, as the figure shows, is largely the result of socio-economic development pathways and societal conditions. Both the changes in the climate system (left side) and the development processes (right side) are key drivers of the different core components (vulnerability, exposure, and physical impacts or hazards) that constitute risk (modified version of Figure 1, IPCC 2012).

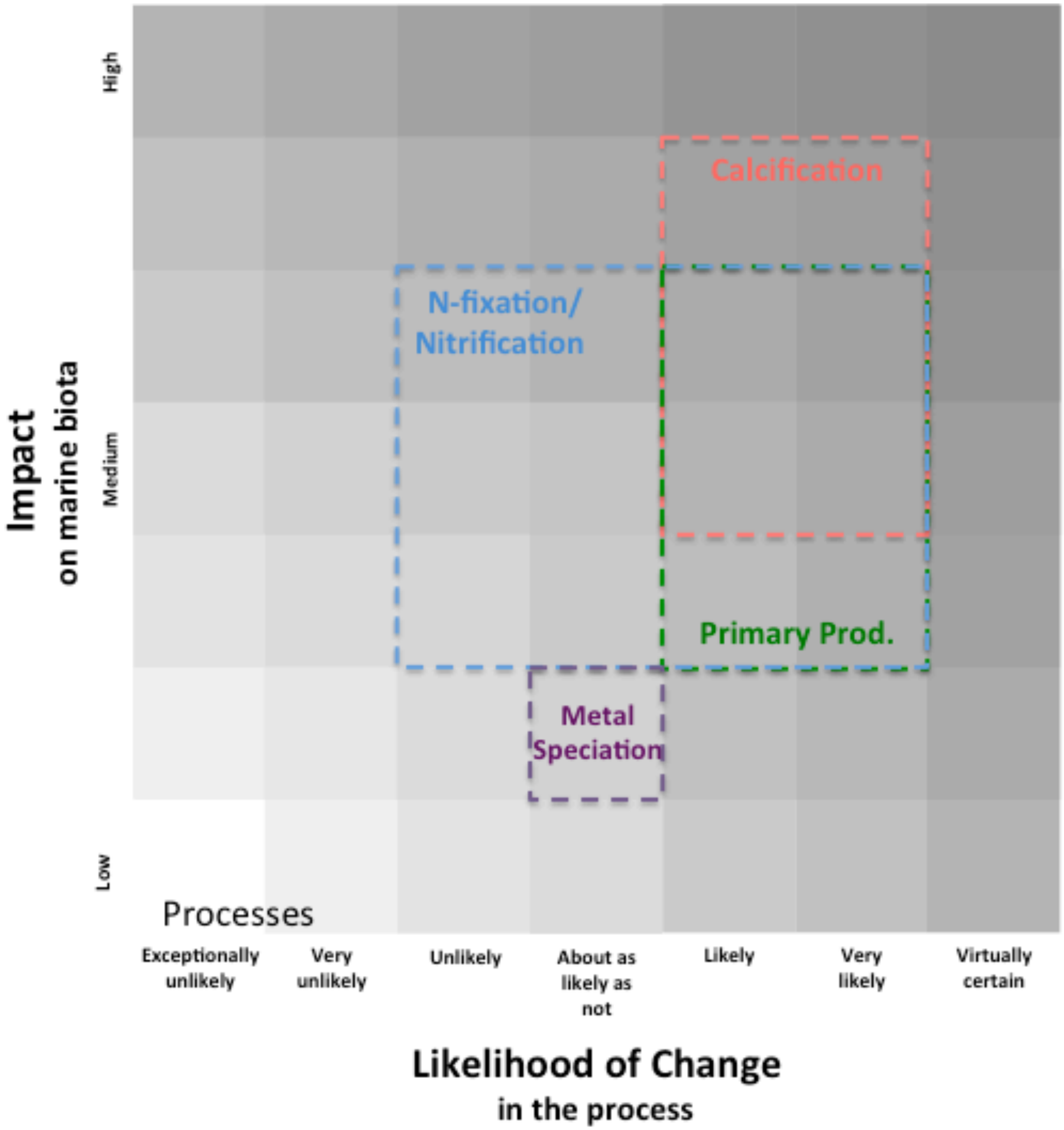

Figure 19-2: Assessment of impacts of ocean acidification on marine organisms through effects on various biogeochemical processes Assessment based on (1) estimated likelihood that the process will be affected by ocean acidification and (2) the magnitude of impacts to marine organisms. The width of the boxes roughly indicates the uncertainty in the likelihood of the process being affected by acidification, while the height of the boxes roughly indicates the magnitude of impacts to marine organisms. Height, width, and location of boxes are based on expert opinion, with greatest subjectivity in judging impacts. Judgments are based on impacts expected with atmospheric CO2 levels of 2-3x preindustrial levels (560-840 ppmv). This figure is meant to be broadly illustrative: with sufficient information Low, Medium, and High would be defined quantitatively. For example, while the sign of the impact on marine calcifiers is negative, the magnitude varies considerably across taxa and currently overall quantification is not feasible (based on a meta-analysis by Kroeker et al. 2010).

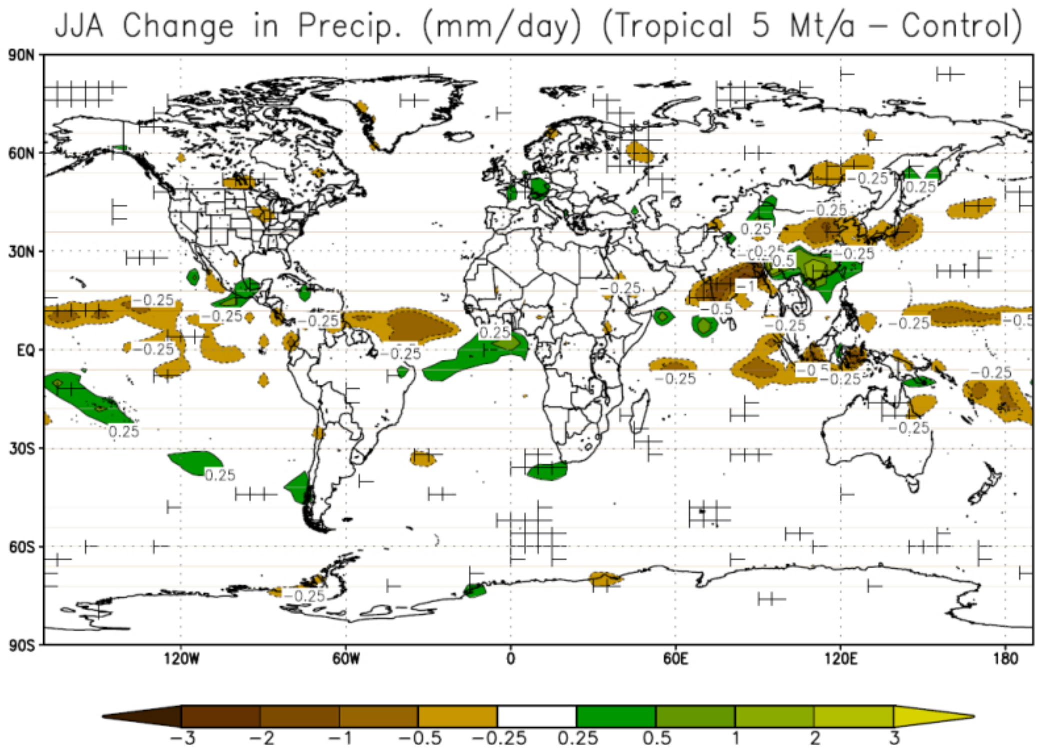

Figure 19-3: Northern Hemisphere summer precipitation differences from the current climate averaged for the second 10 years of a 20-year geoengineering period emitting 5 Mt SO_2 per year into the tropical lower stratosphere combined with A1B (Fig. 8, Robock et al., 2008). Hatch marks indicate changes significant at the 5% level. Note large reductions over India and China.

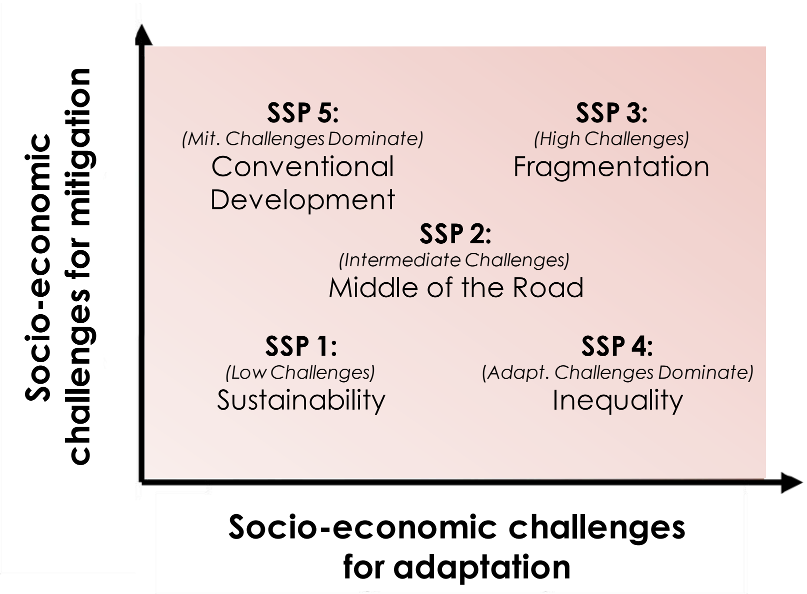

Figure 19-4: Definition of five Shared Socio-economic Pathways (SSPs) describing alternative development pathways that span a range of challenges to adaptation and mitigation (O’Neill et al., 2012).

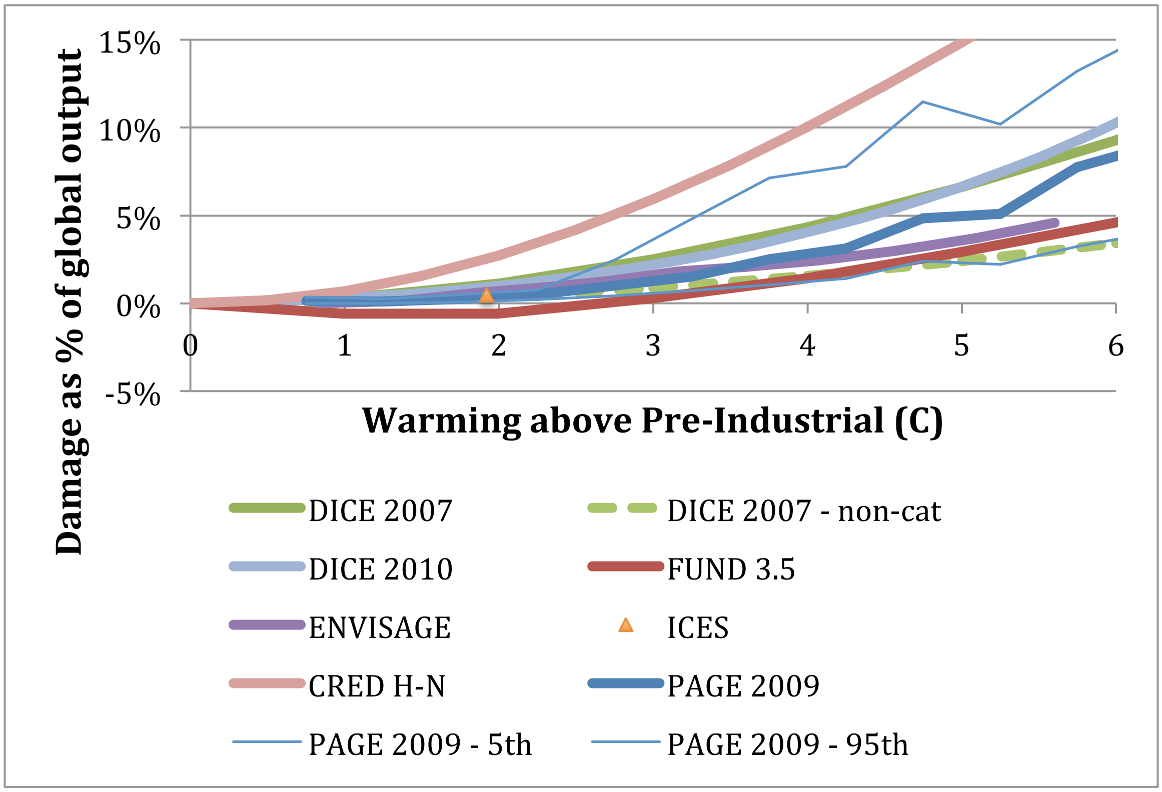

Figure 19-5: Representative global damage estimates, shown as a % of global output as a function of temperature. FUND: (Interagency Working Group on the Social Cost of Carbon, United States Government, 2010). DICE: (Nordhaus, 2008, 2011). PAGE: (Hope, 2011). CRED: (Ackerman et al., 2011). ENVISAGE: (Roson and Mensbrugghe, 2010). ICES: (Bosello et al., 2012). Note that, of models shown, only DICE and CRED (the damage function of which is recalibrated from that of DICE based on (Hanemann, 2008)) and PAGE attempt to include uncertain catastrophic damages, and only ENVISAGE includes labor productivity lost due to heat/humidity. For comparison, DICE 2007 damages are also shown considering only non-catastrophic impacts.

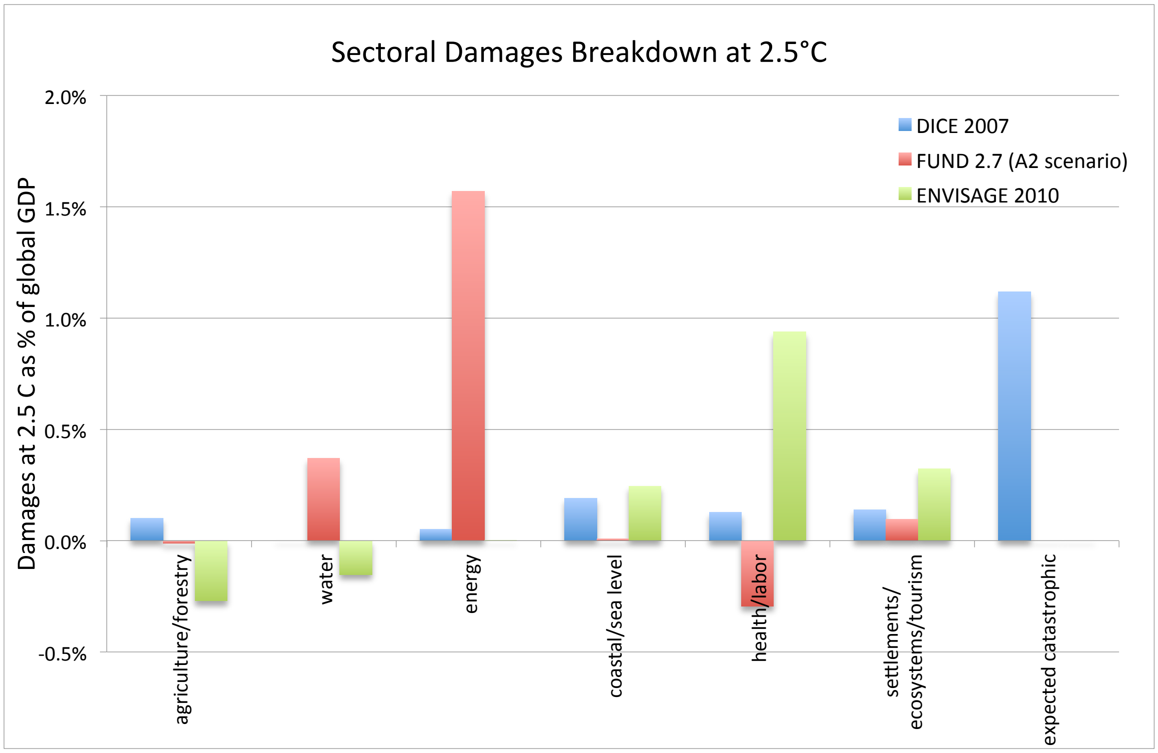

Figure 19-6: Breakdown of damages at 2.5°C above pre-industrial by sector in DICE 2007 (Nordhaus, 2007), FUND 2.7 (Warren et al., 2006) and ENVISAGE (Roson and Mensbrugghe, 2010), reflecting a low level of agreement among the integrated assessment models used to estimate global aggregate damages. Modified from (Kopp and Mignone, 2012). Note that the DICE calibration does not include damages due to changes in water resources as distinct from temperature impacts on agriculture and forestry, and FUND and ENVISAGE do not include expected catastrophic damages. Representations of changes in energy demand, coastal/sea level impacts, health and labor productivity impacts, and impacts on settlements, ecosystem and tourism are included in all three models.

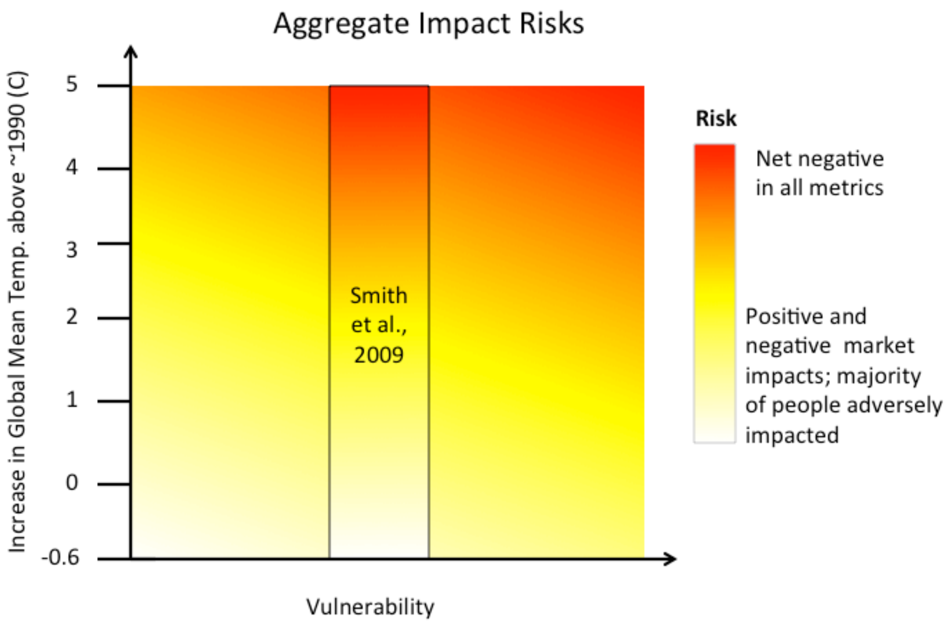

Figure 19-7: Illustration of the dependence of risk associated with the RFC related to aggregate impacts (section 19.6.3.4) on the level of climate change and vulnerability of society. For comparison, the representation from Smith et al. (2009) is shown, which does not explicitly take vulnerability into account. It is assumed here to be based implicitly on a medium level of future vulnerability. If future socio-economic conditions lead to more vulnerable societies, the aggregate impact risks associated with a given level of climate change would be higher. If future conditions lead to less vulnerable societies, risks for a given level of climate change would be lower. This figure is schematic; the specific degree of risk associated with particular levels of climate change has not been based on a literature assessment.

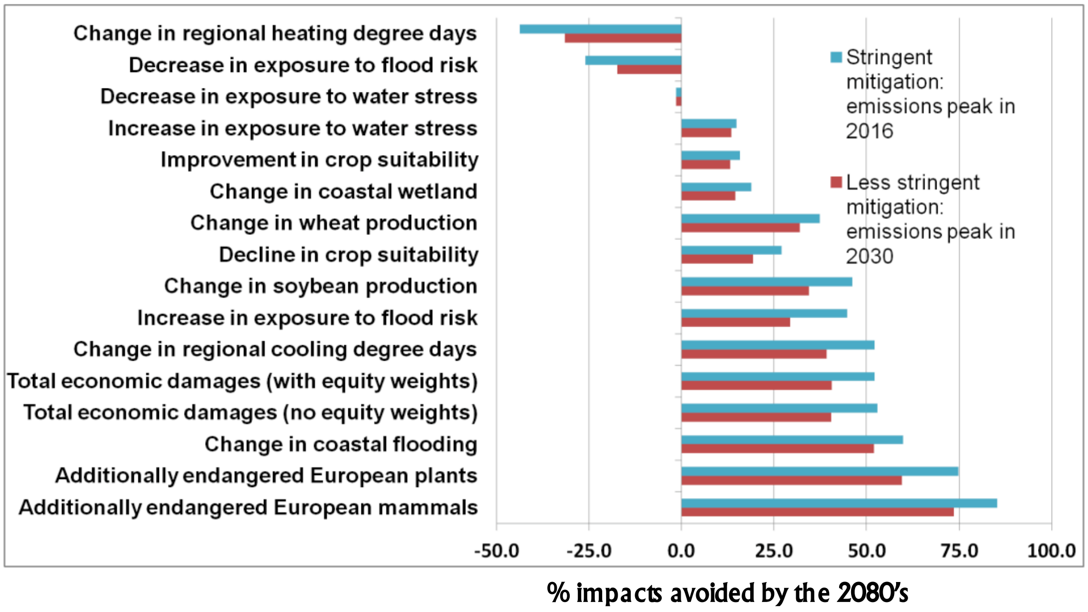

Figure 19-8: Climate change impacts avoided by two different mitigation scenarios compared to a no-mitigation case (SRES A1B scenario). Since increases and decreases in water stress, flood risks and crop suitability are not co-located and affect different regions, these effects are not combined. From Arnell et al 2012.