10. Key Economic Sectors and Services

Coordinating Lead Authors
Douglas Arent (USA), Richard S.J. Tol (UK / The Netherlands)

Lead Authors
Eberhard Faust (Germany), Joseph P. Hella (Tanzania), Surender Kumar (India), Kenneth M. Strzepek (UNU / USA), Ferenc L. Toth (IAEA / Hungary), Denghua Yan (China)

Contributing Authors
Francesco Bosello (Italy), Paul Chinowsky (USA), Kristie L. Ebi (USA), Stephane Hallegatte (France), Philip Ward ( ), Eric Williams ( )

Review Editors
Amjad Abdullah (Maldives), Haroon Kheshgi (USA), He Xu (China)

Contents

Executive Summary

Climate change would reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors (*high agreement, robust evidence*); the balance of the two depends on the geographic, socioeconomic and technological conditions. Increasing income will allow people to regulate indoor temperatures to a comfort level that leads to fast growing energy demand for air conditioning even in the absence of climate change in warm regions with low income levels at present. Energy demand will be influenced by changes in demographics (upwards by increasing population and decreasing average household size), lifestyles (upwards by larger floor area of dwellings), the design and heat insulation properties of the housing stock, the energy efficiency of heating/cooling devices and the abundance and energy efficiency of other electric household appliances. The relative importance of these drivers varies across regions and will change over time. [10.2]

Climate change would affect different energy sources and technologies differently, depending on the resources (water flow, wind, insolation), the technological processes (cooling) or the locations (coastal regions, floodplains) involved (*high agreement, robust evidence*). Gradual changes in various climate attributes (temperature, precipitation, windiness, cloudiness, etc.) and possible changes in the frequency and intensity of extreme weather events will progressively affect operation over time. Climate-induced changes in the availability and temperature of water for cooling are the main concern for thermal and nuclear power plants, but several options are available to cope with reduced water availability. Similarly, already available or newly developed technological solutions allow firms to reduce the vulnerability of new structures and enhance the climate suitability of existing energy installations. [10.2]

Climate change would influence the integrity and reliability of pipelines and electricity grids (*medium agreement, medium evidence*). Pipelines and electric transmission lines have been operated for over a century in diverse climatic conditions on land from hot deserts to permafrost areas and increasingly at sea. Climate change is *about as likely as not* to require the adoption of technological solutions for the construction and operation of pipelines and power transmission and distribution lines from other geographical and climatic conditions, adjustments in existing pipelines and improvements in the design and deployment of new ones in response to the changing climate and weather conditions. [10.2]

Climate change would have impacts, heterogeneous in both sign and size, on water resources and water use (*high agreement, robust evidence*), but the economic implications are not well understood. Economic impacts include flooding, scarcity and cross sectoral competition. Flooding can have major economic costs, both in term of impacts (capital destruction, disruption) and adaptation (construction, defensive investment). Water scarcity and competition for water, driven by institutional, economic or social factors, may mean that water assumed to be available for a sector is not. [10.3]

Climate change would negatively affect transport infrastructure (*high agreement, limited evidence*). Transport infrastructure malfunctions if the weather is outside the design range, which would happen more frequently should climate change. All infrastructure is vulnerable to freeze-thaw cycles and paved roads are particularly vulnerable to temperature extremes, unpaved roads to precipitation extremes. Transport infrastructure on ice or permafrost is especially vulnerable. [10.4]

Climate change would affect tourism resorts, particularly ski resorts, beach resorts, and nature resorts (high agreement, robust evidence) and tourists would be inclined to spend their holidays at higher altitudes and latitudes (*high agreement, medium evidence*). The economic implications of climate-change-induced changes in tourism demand and supply may be substantial, with gains for countries closer to the poles and higher up the mountains and losses for other countries. The demand for outdoor recreation is affected by weather and climate, and impacts will vary geographically and seasonally. [10.6]

Climate change strongly affects insurance systems (*high agreement, robust evidence*). More frequent and/or intensive weather disasters increase losses and loss variability in various regions and challenge insurance systems to offer affordable coverage while raising more risk-based capital, particularly in low- and middle-income countries. Economic-vulnerability reduction through insurance has proven effective. Large-scale public-private risk prevention initiatives and government insurance of the non-diversifiable portion of risk offer example mechanisms for adaptation. Commercial reinsurance and risk-linked securitization markets also have a role in ensuring financially resilient insurance systems. [10.7]

Climate change would affect the health sector (*high agreement, medium evidence*) through increases in the frequency, intensity, and extent of extreme weather events adversely affecting infrastructure and increase the demands for services due to the human health impacts of climate change, placing additional burdens on public health, disease burden, and health care personnel and supplies; these have economic consequences. [10.8]

Markets provide an additional mechanism for adaptation and would thus reduce negative impacts and increase positive ones for any specific sector or country (*high agreement, medium evidence*). The impacts of climate on one sector of the economy of one country in turn affect other sectors and other countries though product and input markets. Markets increase overall welfare, but not necessarily welfare in every sector and country. [10.9]

The impacts of climate change would decrease productivity and economic growth, but the magnitude of this effect is not well understood (*high agreement, limited evidence*). Climate could be one of the causes why some countries are trapped in poverty, and climate change may make it harder to escape poverty traps. [10.9]

Not all key sectors have been subject to detailed research based on a comprehensive assessment across economic sectors. Few studies have evaluated the possible impacts of climate change on mining, manufacturing or services (apart from health, insurance and tourism).Further research, collection and access to more detailed economic data and the advancement of analytic methods and tools will be required to further assess the potential impacts of climate on key economic systems and sectors. [10.5, 10.8, 10.10]

10.1. Introduction and Context

This chapter discusses the implications of climate change on key economic sectors and services; e.g., economic activity. Other chapters discuss impacts from a physical, chemical, biological, or social perspective. Economic impacts cannot be isolated; and therefore, there are a large number of cross-references to other chapters in this report. In some cases, particularly agriculture, the discussion of the economic impacts is integrated with the other impacts.

Focusing on the potential impact of climate change on economic activity, this chapter addresses questions such as: how does climate change affect the demand for a particular good or service? What is the impact on its supply? How do supply and demand interact in the market? What are the effects on producers and consumers?

An inclusive approach was taken, discussing all sectors of the economy. Appendix A shows the list of sectors according to the International Standard Industrial Classification. This assessment reflects the breadth and depth of the state of knowledge across these sectors; many of which have not been evaluated in the literature. We extensively discuss five sectors: Energy (10.2), water (10.3), transport (10.4), tourism (10.6), and insurance (10.7). Other primary and secondary sectors are discussed in 10.5, and 10.8 is devoted to other service sectors. Food and agriculture is addressed in Chapter 7. Sections 10.2 through 10.8 discuss individual sectors in isolation. Markets are connected, however. Section 10.9 therefore assesses the implications of changes in any one sector on the rest of the economy. It also discusses the effect of the impacts of climate change on economic growth and development. Chapter 19 assesses the impact of climate change on economic welfare – that is, the sum of changes in consumer and producer surplus, including for goods and services not traded within the formal economy. This is not attempted here. The focus is on economic activity. Section 10.10 discusses whether there may be vulnerable sectors that have yet to be studied.

Previous assessment reports by the IPCC did not have a chapter on “key economic sectors and services”. Instead, the material assembled here was spread over a number of chapters. AR4 is referred to in the context of the sections below. In some cases, however, the literature is so new that previous IPCC reports did not discuss these impacts at any length.

10.2. Energy

Studies conducted since AR4 and assessed here confirm the main insights about the impacts of climate change on energy demand as reported in the SAR (Acosta Moreno *et al.*, 1995) and reinforced by the TAR (Scott *et al.*, 2001) and AR4 (Wilbanks *et al.*, 2007): ceteris paribus, in a warming world, energy demand for heating will decline and energy demand for cooling will increase; the balance of the two depends on the geographic, socioeconomic and technological conditions. The relative importance of temperature changes among the drivers of energy demand varies across regions and will change over time. Earlier IPCC assessments did not write much about energy supply, but an increasing number of studies now explore its vulnerability, impacts and the adaptation options (Troccoli, 2010); (Ebinger and Vergara, 2011); (USGCRP, 2009). The energy sector will be transformed by climate policy (Bashmakov et al., forthcoming) but impacts of climate changes too will be important for secure and reliable energy supply.

10.2.1. Energy Demand

Most studies conducted since AR4 explore the impacts of climate change on residential energy demand, particularly electricity. Some studies encompass the commercial sector as well but very few deal with industry and agriculture. In addition to a few global studies based on global energy or integrated assessment models, the new studies tend to focus on specific countries or regions, rely on improved methods (more advanced statistical techniques) and data (both historical and regional climate projections), and many of them explicitly include non-climatic drivers of energy demand. A few studies consider changes in demand together with changes in climate-dependent energy sources, like hydropower.

Figure 10-1 sorts the assessed studies according to the present climate (represented by mean annual temperature) and current income (represented by GDP per capita). Neither indicator is ideal: country-level mean annual temperatures for large countries can hide large regional differences and average incomes may conceal large disparities, but they help cluster the national and regional studies in the search for general findings (Toth, 2013).

[INSERT FIGURE 10-1 HERE
Figure 10-1: GDP per capita (in 2009) and annual mean temperature (based on 1971-2000 climatology) in selected countries and US federal states. Source: Toth, 2013.]

The general patterns are (i) in countries and regions with already high incomes, climate-related changes in energy demand will be primarily driven by increasing temperatures, with associated heavier use of air-conditioning in warm climates, and (ii) lower demands for various energy forms (electricity, gas, coal, oil) in temperate and cold climates, while increasing incomes will play a marginal role. In contrast, changes in income will be the main driver of increasing demand for energy (mainly electricity for air conditioning and transportation fuels) in present-day low-income countries in warm climates.

At the global scale, energy demand for residential air conditioning in summer is projected to increase rapidly in the 21st century under the reference climate change scenario (medium population and economic growth globally, but faster economic growth in developing countries; no mitigation policies in addition to those in place in 2008) by the TIMER/IMAGE model (Isaac and Van Vuuren, 2009). The increase is from nearly 300 TWh in 2000, to about 4,000 TWh in 2050 and more than 10,000 TWh in 2100, about 75% of which is due to increasing income in emerging market countries and 25% is due to climate change. Energy demand for heating in winter increases too, but much less rapidly, since in most regions with the highest need for heating, incomes are already high enough for people to heat their homes to the desired comfort level (except in some poor households). In these regions, energy demand for heating will decrease.

These general patterns and especially the quantitative results of the projected shifts in energy and electricity demand can be modified by many other factors. In addition to changes in temperatures and incomes, the actual energy demand will be influenced by changes in demographics (upwards by increasing population and decreasing average household size), lifestyles (upwards by larger floor area of dwellings), the design and insulation of the housing stock, the energy efficiency of heating/cooling devices, the abundance and energy efficiency of other selectric household appliances, the price of energy, etc.

10.2.2. Energy Supply

Changes in various climate attributes (temperature, precipitation, windiness, cloudiness, etc.) will affect different energy sources and technologies differently. Gradual climate change (CC) will progressively affect operation over time. Possible changes in the frequency and intensity of extreme weather events (EWEs) represent a different kind of hazard for energy installations and infrastructure. This section assesses the most important impacts and adaptation options in both categories. Table 10-1 provides an overview.

[INSERT TABLE 10-1 HERE
Table 10-1: Main projected impacts of CC and EWEs on energy supply.]

Currently, thermal power plants provide about 80% of global electricity and their share is projected to remain high in most mitigation scenarios (IEA, 2010aa). Thermal power plants are operated under diverse climatic conditions from the cold Arctic to the hot tropical regions and are well adapted to the prevailing conditions. However, they might face new challenges and will need to respond by hard (design or structural methods) or soft (operating procedures) measures as a result of climate change.

The most significant impact of CC on thermal power generation is the decreasing efficiency of thermal conversion as a result of rising temperature. This follows from Carnot's rule and cannot be offset per se. Yet there is much room to improve the efficiency of currently operating subcritical steam power plants (IEA, 2010b). As new materials allow higher operating temperatures in coal-fired power plants (Gibbons, 2012), supercritical and ultra-supercritical steam-cycle plants will reach even higher efficiency that can more than compensate the efficiency losses due to higher temperatures. Yet in the absence of CC, these efficiency gains from improved technology would reduce the costs of energy, so there is still a net economic loss due to CC. Another problem facing thermal power generation in many regions is the decreasing volume and increasing temperature of water for cooling, leading to reduced power generation, operation at reduced capacity and even temporary shutdown of power plants (Ott and Richter, 2008; Hoffmann *et al.*, 2010; IEA, 2012; Nee Schulz, 2012). Both problems will be exacerbated if CO_2 capture and handling equipment is added to fossil-fired power plants: energy efficiency declines by 8-14 % and water requirement per MWh electricity generated can double (IPCC, 2005).

Adaptation possibilities range from relatively simple and low-cost options like exploiting non-traditional water sources and re-using process water to measures like installing dry cooling towers, heat pipe exchangers and regenerative cooling (Ott and Richter, 2008; De Bruin *et al.*, 2009), all which increase costs. While it is easier to plan for changing climatic conditions and select the conforming cost-efficient cooling technology for new builds, response options are more limited for existing power plants, especially for those towards the end of their economic lifetime.

CC impacts on thermal efficiency and cooling water availability affect nuclear power plants similarly to their thermal counterparts (Williams and Toth, 2013). Whereas there is no escape from Carnot's rule affecting efficiency, a range of alternative cooling options are available to deal with water deficiency, ranging from re-using wastewater and recovering evaporated water (Feeley III *et al.*, 2008) to installing dry cooling (EPA , 2001).

The implications of EWEs for nuclear plants can be severe if not properly addressed. Reliable interconnection (onsite power and instrumentation connections) of intact key components (reactor vessel, cooling equipment, control instruments, back-up generators) is indispensable for the safe operation and/or shutdown of a nuclear reactor. For most of the existing global nuclear fleet, a reliable connection to the grid for power to run cooling systems and control instruments in emergency situations is another crucial item (IAEA (International Atomic Energy Agency), 2011). Several EWEs can damage the components or disrupt their interconnections. Preventive and protective measures include technical and engineering solutions (circuit insulation, shielding, flood protection) and adjusting operation to extreme conditions (reduced capacity, shutdown) (Williams and Toth, 2013).

Hydropower is by far the largest of renewable energy sources in the current energy mix. It is projected to remain important in the future, irrespective of the climate change mitigation targets in many countries (IEA, 2010aa; IEA, 2010b). The resource base of hydropower is the hydrologic cycle driven by prevailing climate and topology. The former makes the resource base and hence hydropower generation highly dependent on future changes in climate and related changes in extreme weather events (Ebinger and Vergara, 2011; Mukheibir, 2013).

Assessing the impacts of climate change on hydropower generation is the most complex endeavour in the energy sector. A series of non-linear and region-specific changes in mean annual and seasonal precipitation and temperatures, the resulting evapotranspiration losses, shifts in the share of precipitation falling as snow and the timing of its release from high elevation make resource estimates difficult (see Chapters 2 and 3) while regional changes in water demand due to changes in population, economic activities (especially irrigation demand for agriculture) present competition for water resources that are hard to project (see Section 10.3). Further complications stem from the possibly increasing need to combine hydropower generation with changing flood control and ecological (minimum dependable flow) objectives induced by changing climate regime.

Focusing on the possible impacts of CC on hydroelectricity and the adaptation options in the sector in response to the changes in the amount, the seasonal and inter-annual variations of available water, and in other demands, the overall conclusion from the literature is that the impacts of CC and EWEs on hydropower generation is *likely* to increase in most regions and decrease in some, with diverging patterns across regions, watersheds within regions and even river basins within watersheds. Planning tools for long-term hydrogeneration may need to be enhanced to cope with slow but persistent shifts in water availability, and short-term management models may need to be enhanced to deal with the impacts of EWEs. A series of hard (raising dam walls, adding bypass channels) and soft (adjusting water release) measures are available to protect the related infrastructure (dams, channels, turbines, etc.) and optimize incomes by timing generation when electricity prices are high (Mukheibir, 2013).

Solar energy is expected to increase from its currently small share in the global energy balance across a wide range of mitigation scenarios (IEA, 2008; IEA, 2010aa; IEA, 2010ab; IEA, 2010ab; IEA, 2010b). The three main types of technologies for harnessing energy from insolation include thermal heating (TH) (by flat plate, evacuated tube and unglazed collectors), photovoltaic (PV) cells (crystalline silicon and thin film technologies) and concentrating solar power (CSP) (power tower and power trough producing heat to drive a steam turbine for generating electricity). The increasing body of literature exploring the vulnerability and adaptation options of solar technologies to CC and EWEs is reviewed by (Patt *et al.*, 2013).

All types of solar energy are sensitive to changes in climatic attributes that directly or indirectly influence the amount of insolation reaching them. If cloudiness increases under climate change (see Chapters 11 and 12 of the WGI report), the intensity of solar radiation and hence the output of heat or electricity would be reduced. Efficiency losses in cloudy conditions are less for technologies that can operate with diffuse light (evacuated tube collectors for TH, PV collectors with rough surface). Since diffuse light cannot be concentrated, CSP output would cease under cloudy conditions but the easy and relatively inexpensive possibility to store heat reduces this vulnerability if sufficient volume of heat storage is installed (Khosla, 2008; Richter *et al.*, 2009).

The exposure of sensitive material to harsh weather conditions is another source of vulnerability for all types of solar technologies. Windstorms can damage the mounting structures directly and the conversion units by flying debris, whereby technologies with smaller surface areas are less vulnerable. Hail can also cause material damage and thus reduced output and increased need for repair. Depending on regional conditions, strong wind can deposit sand and dust on the collectors' surface, reducing efficiency and increasing the need for cleaning.

CC and EWE hazards per se do not pose any particular constraints for the future deployment of solar technologies. Technological development continues in all three solar technologies towards new designs, models and materials. One of the objectives of these development efforts is to make new models less vulnerable to current climate and EWEs. Technological development also results in a diverse portfolio of models to choose from according to the climatic and weather characteristics of the deployment site. These development efforts can be integrated in addressing the key challenge for solar technologies today: reducing the costs.

Harnessing wind energy for power generation is an important part of the climate change mitigation portfolio in many countries. Assessing the possible impacts of CC and EWEs on this technology and exploring possible adaptation options are complicated by the complex dynamics characterizing wind energy. Relevant attributes of climate are expected to change; the technology is evolving (blade design, other components); see (Kong *et al.*, 2005; Barlas and Van Kuik, 2010); there is an increasing deployment offshore and a transition to larger turbines (Garvey, 2010) and to larger sites (multi megawatt arrays) (Barthelmie *et al.*, 2008).

The key question concerning the impacts of a changing climate regime on wind power is related to the resource base: how climate change will rearrange the temporal (inter- and intra-annual variability) and spatial (geographical distribution) characteristics of the wind resource. (Pryor and Barthelmie, 2010) find that in the next few decades wind resources (measured in terms of multi-annual wind power densities) are estimated to remain within the ±50% of the values compared to the past 20 year mean values. The wide range of the estimates results from the circulation and flow regimes in different GCMs and regional climate models (RCMs) (Bengtsson *et al.*, 2006; Pryor and Barthelmie, 2010). A set of four GCM-RCM combinations for the period 2041-2062 indicates that average annual mean energy density will be within ±25% of the 1979-2000 values in all 50 km grid cells over the contiguous USA (Pryor *et al.*, 2011(a); Pryor and Barthelmie, 2013). Yet, little is known about changes in the inter-annual, seasonal or diurnal variability of wind resources.

Wind turbines already operate in diverse climatic and weather conditions. As shown in Table 10-1, siting, design and engineering solutions are available to cope with various impacts of gradual changes in relevant climate attributes over the coming decades. The requirements to withstand extreme loading conditions resulting from climate change are within the safety margins prescribed in the design standards, although load from combinations of extreme events may exceed the design thresholds (Pryor and Barthelmie, 2013). In summary, the wind energy sector does not face insurmountable challenges resulting from climate change.

In the coal fuel cycle, vulnerability in mining depends on the mining method. Open cast mining might be particularly affected by high precipitation extremes and related floods and erosion, and temperature extremes, especially extreme cold that might encumber extraction for some time, whereas impacts on coal cleaning and operation of underground mines will probably be less severe. Changes in drainage and run-off regulation for on-site coal storage as well as in coal handling might be required due to the increased moisture content of coal and more energy might be required for coal drying before transportation (CCSP, 2007). Using current carbon dioxide capture technologies would almost double water consumption per unit of electricity generated from coal-fired plants, exacerbating water supply problems in water-stressed regions and/or seasons. At the back end of the fuel cycle, the management of fly-ash, bottom ash and boiler slag may need to be modified in response to changes in some EWE patterns like wind, precipitation and floods.

Climate and weather related hazards in the oil and gas sector include tropical cyclones with potentially severe effects on off-shore platforms and on-shore infrastructure as well, leading to more frequent production interruptions and evacuation (Cruz and Krausmann, 2013). Gradual changes in air temperature and precipitation are projected to generate risk and opportunities for the oil and gas industry. For example, reduced sea ice thickness and coverage might open new shipping routes, thus reducing shipping costs, while ice scour and ice pack loading on marine structures would increase. However, most changes involve increased risks, such as thawing permafrost would increase construction costs on unstable ground relative to ice-based construction, while thaw subsidence would trigger increased maintenance costs. Sea level rise and coastal erosion would degrade coastal barriers, damage facilities and trigger relocation (Dell and Pasteris, 2010).

10.2.3. Transport and Transmission of Energy

Primary energy sources (coal, oil, gas, uranium), secondary energy forms (electricity, hydrogen, warm water) and waste products (CO_2, coal ash, radioactive waste) are transported in diverse ways to distances ranging from a few to thousands of kilometres. The transport of energy-related materials by ships (ocean and inland waters), rail and road are exposed to the same impacts of climate change as the rest of the transport sector (see Section 10.4). This subsection deals only with transport modes that are unique to the energy sector (power grid) or predominantly used by it (pipelines). Table 10-2 provides an overview of the impacts of CC and EWEs on energy transmission, together with the options to reduce vulnerability.

[INSERT TABLE 10-2 HERE
Table 10-2: Main impacts of CC and EWEs on pipelines and the electricity grid.]

Pipelines play a central role in the energy sector by transporting oil and gas from the wells to processing and distributing centres to distances from a few hundred to thousands of kilometres. With the spread of CO_2 capture and storage (CCS) technology, another important function will be to deliver CO_2 from the capture site (typically fossil power plants) to the disposal site onshore or offshore. Pipelines have been operated for over a century in diverse climatic conditions on land from hot deserts to permafrost areas and increasingly at sea. This implies that technological solutions are available for the construction and operation of pipelines under diverse geographical and climatic conditions. Yet adjustments may be needed in existing pipelines and improvements in the design and deployment of new ones in response to the changing climate and weather conditions.

Pipelines will be mainly affected by secondary impacts of climate change: sea-level rise in coastal regions, melting permafrost in cold regions, and floods and landslides triggered by heavy rainfall. A proposed way to reduce vulnerability to these events is the amendment of land zoning codes, and the design and construction standards for new pipelines and structural upgrade for existing ones (Antonioni *et al.*, 2009; Cruz and Krausmann, 2013).

Due to the very function of the electricity grid to transmit power from generation units to consumers, the bulk of its components (overhead lines, substations, transformers) are located outdoors and exposed to EWE. The power industry has developed numerous technical solutions and related standards to protect those assets and provide reliable electricity supply under prevailing climate and weather conditions worldwide; however, much existing infrastructure is vulnerable to EWEs.

Higher average temperatures decrease transmission efficiency by about 0.4%/°C but this effect is relatively small compared to the physical and monetary damages that can be caused by EWEs (Ward, 2013). Historically, high wind conditions, including storms, hurricanes and tornados, have been the most frequent cause of grid disruptions (mainly due to damages to the distribution networks), and more than half of the damage was caused by trees (Reed, 2008). If the frequency and power of high wind conditions, as well as extreme precipitation events, will increase in the future, vegetation management along existing power lines and rerouting new transmission lines along roads or across open fields might help reduce related risks.

The economic importance of a reliable transmission and distribution network is highlighted by the fact that the damage to customers tend to be much higher than the price of electricity not delivered (lost production, electricity enabled commerce, service delivery, food spoilage, lost or restricted water availability). Designing and building climate-resilient infrastructure will depend on technical standards, market governance, and the type and degree of liberalization and deregulation of grid services.

10.2.4. Macroeconomic Impacts

Most economic research related to climate change impacts on the energy sector has focused on mitigation rather than the economic implications of climate change itself. Table 10-3 summarizes the recent studies on the economic implications of climate change and extreme weather impacts in the energy sector.

[INSERT TABLE 10-3 HERE
Table 10-3: Economy-wide implications of impacts of climate change and extreme weather on the energy sector.]

Assessing across a broad array of studies that focus on different regions and regional divisions, examine different climate change impacts, include a different mix of sectors, model different timeframes, make different assumptions about adaptation, and employ different types of models with different output metrics leads to the overall conclusion that the macroeconomic impact of climate change on energy demand is *likely* to be minimal in developed countries (Bosello *et al.*, 2007; Aaheim *et al.*, 2009; Bosello *et al.*, 2009; Jochem *et al.*, 2009; Jochem *et al.*, 2009; Eboli *et al.*, 2010a).

The current literature sheds less light on the implications for developing countries and on other climate impacts in the energy sector beyond those related to changes in energy demand. Europe is the focus of most of the literature so far. Asia, Africa, and Latin America are not well represented, appearing in only two global studies. The limited results indicate that developing countries *likely* face a greater negative GDP impact with respect to climate change implications for the energy sector than developed countries (Aaheim *et al.*, 2009; Boyd and Ibarraran, 2009; Eboli *et al.*, 2010a).

Despite the considerable number of potential climate change and extreme weather phenomena – higher mean temperatures, changes in rainfall patterns, changes in wind patterns, changes in cloud cover and average insolation, lightning, high winds, hail, sand storms and dust, extreme cold, extreme heat, floods, drought, and sea-level rise – and their potential impacts on electricity generation and transmission systems, fuel infrastructure and transport systems, and energy demand (Williams, 2013) – the range of impacts modeled in the literature (Table 10-3) is quite limited. Most studies consider changing energy demand (specifically, changes in electricity and fuel consumption for space heating/cooling) resulting from rising temperatures as the only or primary climate change impact. These studies draw upon recent literature refining the relationship between climate change and energy demand: the demand for natural gas and oil in residential and commercial sectors tends to decline with climate change because of less need for space heating, and demand for electricity tends to increase because of greater need for space cooling (Gabrielsen *et al.*, 2005; Gabrielsen *et al.*, 2005; Kirkinen *et al.*, 2005; Mansur *et al.*, 2005; Gunnar and Torben, 2010; Mideksa and Kallbekken, 2010; Rübbelke and Vögele, 2010).

Studies using a computable general equilibrium (CGE) model that consider only climate impacts in the energy sector find that the effect on GDP in 2050 is quite modest at -0.3% to 0.03% (Bosello et al. 2007) and -1.3% to -0.6% (Jochem *et al.*, 2009). These findings are largely consistent despite the fact that (Bosello *et al.*, 2007; Bosello *et al.*, 2009) are global studies that model only the change in demand due to rising temperatures, whereas (Jochem *et al.*, 2009) focus on the EU and model the change in demand plus six other climate impacts.

Studies using CGE models that examine the aggregate changes in GDP brought on by climate impacts in energy and several other sectors have also primarily found moderate shifts in GDP. (Aaheim *et al.*, 2009) conclude that in 2100 in cooler regions in the EU, GDP changes by -1% to -0.25% and in warmer regions changes by -3% to -0.5%. (Boyd and Ibarraran, 2009) project a -3% change in GDP in 2026 for Mexico, consistent with the warmer regions modeled by (Aaheim *et al.*, 2009). Roughly consistent with each other (Aaheim *et al.*, 2009; Eboli *et al.*, 2010a) find GDP impacts for the predominantly cooler regions of Japan, the EU, EEFSU, and Rest of Annex I as having a “significant positive impact”, while the predominantly warmer regions of the USA, EEx (China/India, Middle East/Most of Africa/Mexico/parts of Latin America), and the Rest of the World have a “significantly negative impact.” (Jorgenson *et al.*, 2004) find that overall GDP impacts are -0.6% to 0.7% in 2050 for the United States, which stands in contrast to (Eboli *et al.*, 2010a) with a “significantly negative impact” in the United States.

Several CGE studies attempt to evaluate how adaptation changes in the energy sector impact GDP but do not examine specific adaptation options since CGE models lack the necessary technological detail. They make general assumptions about the effectiveness of adaptation policy in reducing climate impacts. (Jorgenson *et al.*, 2004) find that pessimistic assumptions about adaptation imply a 0.6% reduction in GDP in 2050 but optimistic assumptions lead to a 0.7% gain in GDP. (Aaheim *et al.*, 2009) conclude that adaptation can mitigate the costs of climate change by 80% to 85%, and (Boyd and Ibarraran, 2009) find that adaptation can shift a 3% GDP loss in 2026 in Mexico to a gain in GDP of 0.33%.

Partial equilibrium models, by their nature, do not have a full macroeconomic representation and therefore rarely report changes in GDP. Instead, these models focus on details in the energy sector, such as price and quantity effects for fuels and electricity (and the mix of generation). (Golombek *et al.*, 2011) report a 1% increase in the price of electricity for Western Europe in 2030 stemming from rising temperatures that affect demand and thermal efficiency of supply, as well as water inflow. (Gabrielsen *et al.*, 2005) conclude that for Nordic countries in 2040, as a result of rising temperatures that affect demand, changes in water inflow, and changes in wind speeds, the price of electricity will decline by 1%. Although the change in price differs in sign, the magnitude of change is small in both studies. In contrast, (Bye *et al.*, 2006) in looking at a hypothetical water shortage scenario in Nordic countries, conclude that the price of electricity can double over a 2 year period and then return to normal as water flow returns. (DOE, 2009) also finds that a drought scenario can lead to average monthly electricity prices that are 8.1% (November) to 24.1% (July) higher. In contrast to the significant price impacts found by (Bye *et al.*, 2006) and (DOE, 2009), (Koch *et al.*, 2012) conclude that thermal plant outages in Berlin resulting from heat wave-driven water temperatures that exceed regulatory limits can amount to a cumulative cost of 60 million EURO over the period 2010 through 2050 for 2850 MW of capacity. Assuming an 80% capacity factor, the premium for high water temperatures in Berlin is 0.075 EURO per MWh.

10.2.5. Summary

The balance of evidence emerging from the literature assessed in this section suggests that climate change per se will *likely* increase the demand for energy in most regions of the world. At the same time, increasing temperature will decrease the thermal efficiency of fossil, nuclear and solar power generation, the potential and dependability of hydropower, etc. However, temperature-induced impacts on energy supply will probably make a relatively small contribution to the overall increase in demand for energy and electricity. Similarly, CC impacts on energy supply will be part of an evolving picture dominated by technological development in the pursuit for safer, cheaper and more reliable energy sources and technologies as well as mitigation and adaptation response pathways.

Given the limitations in the literature, sweeping conclusions about results may be premature on macroeconomic implications. However, some narrow conclusions are possible. The change in GDP due to temperature-induced changes in energy demand – even if combined with other climate impacts – is relatively small in all of the studies. Ranging from -3% to 1.2%. (Jochem *et al.*, 2009) which is the most detailed and comprehensive study, report only a 1.3% drop in GDP in 2050 in Europe due to at least seven climate impacts in the energy sector. The GDP impact in warmer regions tends to be greater than in cooler regions, which benefit from less need for space cooling. Energy related economic impact for developing countries is anticipated to be negative, and positive in developed countries. Adaptation can lower the cost of climate change, but these results may be driven largely by assumption since specific policies have not been modeled. Results from some of the partial equilibrium models suggests that CGE modeling studies, which largely focus on changes in energy demand, may be neglecting some potentially costly impacts from extreme weather events like drought, which, if modeled, may lead to greater GDP impacts than reported thus far in the literature.

Much research is still needed to understand the implications of climate change and extreme weather on the energy sector and to identify cost-effective adaptation options. The best understood area is the implications of climate on energy demand. A comprehensive evaluation of a full range of supply-side climate change impacts and adaptation options for all aspects of energy infrastructure is needed. This information will help modelers make much better, empirically-based assumptions about the relationship of climate impacts and the economy, as well as about the effectiveness of adaptation options. Expanding research into developing countries is also much needed, as developing countries are more vulnerable to climate change impacts and probably face more significant economic implications.

10.3. Water

This section focuses on economic aspects of climate change in water related economic sectors. The biophysical water system, including infrastructure, is assessed in Chapter 3.

10.3.1. Water-Related Economic Losses

Between the 1950s and the 1990s, the annual economic losses from large extreme events, including floods and droughts, increased tenfold, with developing countries being hardest hit (Kabat *et al.*, 2003). Over the past few decades, flood damage constitutes about a third of the economic losses inflicted by natural hazards worldwide (Munich Re, 2005). The economic losses associated with floods worldwide have increased by a factor of five between the periods 1950-1980 and 1996-2005 (Kron and Berz, 2007). From 1990 to 1996 alone, there were six major floods throughout the world in which the number of fatalities exceeded 1,000, and 22 floods with losses exceeding US$1 billion each (Kabat et al., 2003). Although these increases are primarily due to several non-climatic drivers, climatic factors are also partly responsible (Kundzewicz *et al.*, 2007). SREX Chapter 4 {{1867 IPCC 2012}} provides a comprehensive look at the impacts of extreme events on water suppl(IPCC, 2012)y and flooding at wide range of spatial scales.

Most of the studies examining the economic impacts of climate change on the water sector have been carried out at the local, national, or river-basin scale; and, the global distribution of such studies is skewed towards developed countries (Schreider *et al.*, 2000; Chen *et al.*, 2001; Middelkoop *et al.*, 2001b; Choi and Fisher, 2003; Hall *et al.*, 2005). In other studies, the economic impacts of climate variability on floods and droughts in developing countries were reported as substantial. For example, the cost to Kenya of the floods associated with the 1997/8 El Niño and the drought associated with the 1998-2000 La Niña, show a cost to the country of 11% and 16% of GDP, respectively (Mogaka *et al.*, 2006). Floods and droughts are estimated to cost Kenya about 2.4% of GDP annually at mid-century, and water resources degradation a further 0.5% (Mogaka *et al.*, 2006). For Ethiopia, economy-wide models incorporating hydrological variability show a drop in projected GDP growth by up to 38% compared to when hydrological variability is not included (World Bank, 2006). However, it is not hydrological variability per se that causes the problem, but rather a lack of the necessary capacity, infrastructure, and institutions to mitigate the impacts (Grey and Sadoff, 2007). Similarly, future flood damages will depend not only on changes in the climate regime, but also on settlement patterns, land use decisions, flood forecasting quality, warning and response systems, and other adaptive measures (Pielke and Downton, 2000; Changnon, 2005; Ward *et al.*, 2008). In many developing countries, water related impacts are *likely* to be more pronounced with climate change (Chapter 3) and associated economic costs can be expected to be more substantial in the future, holding all other factors constant.

The Association of British Insurers (ABI) estimated the financial costs of climate change using insurance catastrophe models in the UK and across Europe. They found that climate change could increase the annual cost of flooding in the UK almost 15-fold by the 2080s under high emission scenarios. If climate change increased European flood losses by a similar magnitude, they estimate that costs could increase by up to $120-150 billion, for the same high emission scenarios (ABI, 2005). (Feyen *et al.*, 2012) project average annual damage in the EU to increase to Euro14-21.5 billion by 2100 depending on the scenario, compared to Euro6.4 billion today. Wobus et al., 2013, estimate an increase in continental US mean annual flood damages of $5 billion and $12 billion in 2050 and 2100, respectively.(Ntelekos *et al.*, 2010) estimate a range of $7-19 billion, depending on the economic growth rate and the emissions scenarios. Dasgupta et al report that by 2050 Bangladesh will face incremental cost to flood protection (against both sea and river floods) of $2.6 billion initial costs and $54 million annual recurring costs. (Ward *et al.*, 2008) found that the average annual costs to adapt to a 1in 50 year river flood to range from $3.5 to $6.0 billion per year for low- to upper-middle-income countries over the period 2010–50 for the A2 scenario.

10.3.2. Municipal and Industrial Water Supply

Beyond flood and other extreme event damages, municipal and industrial water supply economic systems are also impacted through anticipated changes in precipitation patterns and quantities. Economically, these impacts are evaluated as current costs of building in resiliency to the system to adapt to anticipated future changes. For example, the costs of adaptation to maintain supply and quality of water for municipal and industrial uses have been reported for the Assabet River near Boston (Kirshen *et al.*, 2006), Toronto (Dore and Burton, 2001) and Quito (Vergara *et al.*, 2007). Since much of this infrastructure has an economic and engineering life of less than 25 years, building flexibility into these systems is in most cases the best action now. (Nassopoulos *et al.*, 2012) suggest that neglecting to account for future climate change while designing water supply reservoirs can cost 0.2 to 2.8% of the net present value, based on analysis for Greece. For sub-Saharan Africa, adapting urban water infrastructure (storage facilities, wastewater, and additional supply infrastructure) to a 30% reduction in runoff could be $2-5 billion per year (Muller, 2007). Climate change impacts on the Berg River in South Africa are estimated to account for 15% revenue loss for the water supply provider (Callaway et al 2012). For the OECD, the cost of adaption in the water supply sector is 1-2% of base costs and would save $6-12 billion per year (Hughes *et al.*, 2010). U.S. impacts are estimated to be less than 1% of municipal and industrial welfare (Hurd *et al.*, 2004) (Strzepek et al. 2013). In Colorado, a 30% decrease in annual runoff will result in a 12% treatment cost increase and a 22% rise in residential costs (Towler et al, 2011).

On a global scale, (Ward *et al.*, 2010) estimate the adaptation costs to provide enough raw water to meet future global industrial and municipal water demand, based on country-level demand projections to 2050. Increased demand is assumed to be met through a combination of increased reservoir yield and alternative backstop measures. The global adaptation costs are estimated to be US$12B/yr (on top of US$73B/yr to meet the needs of development), with 83-90% in developing countries; the highest costs are in Sub Saharan Africa, and may be as high has 16% of total global adaptation costs. The global cost estimates of climate-change related adaptation in the water resources sector amount to 0.04–0.06 percent of world GDP. Adding resilient adaptive measures to water infrastructure adds 10-20% to the total costs of developing countries meeting the water related millennium goals which is estimated to be only 0.33 percent of GDP, but may help avoid future economic losses. .

10.3.3. Wastewater and Urban Stormwater

More frequent heavy rainfall events may overload the capacity of sewer systems and water and wastewater treatment plants more often, and increased occurrences of low flows will lead to higher pollutant concentrations. While no studies have been conducted on the potential economic losses associated with these systems, estimates of the annual costs of adaptation have been reported. For example, for urban sewers, average over 17 climate models, is $3.0 billion per year in low- to upper-middle-income nations over the period 2010–50 for the A2 scenario (Hughes *et al.*, 2010). Similarly, the cost of building and maintaining additional storm water storage capacity in Canada necessary to manage a 100-year, 24-hour storm is $0.1-2 billion present value for 2010-2100 with a 3% discount rate (Price et al. 2010). Adaptation costs estimates (for a 10-year, 24-hour storm in 2100) for various locations in the USA are relatively low; e.g., $135 million for Los Angeles, $7 million for Boston and $40 million for Chicago (Neumann et al 2013). Bridges are also vulnerable to flood damage, and (Wright *et al.*, 2012) estimate adaptation costs of $140-250 billion in the USA through the 21st century.

10.3.4. Energy: Hydropower and Cooling Water

Using partial equilibrium river basin models, (Hurd *et al.*, 2004) (Strzepek et al. 2013) estimate USA welfare loses due thermal cooling water changes at $622 million per year up to 2100, a 6.5 % welfare loss in the energy sector. (Van Vliet *et al.*, 2012) find that the southeastern United States, Europe, eastern China, southern Africa and southern Australia could potentially be affected by reduced water available for thermoelectric power and drinking water, inducing changes to dry or hybrid cooling (with concomitant loss in electric output), or plant shut downs, with associated impacts on local and regional economic activity. For hydropower locations, adaption to climate change to maintain output has been reported; in Ethiopia, (Block and Strzepek, 2012) report that capital expenditures through 2050 may either decrease by ~3% under extreme wet scenarios, or increase by up to 4% under a severe dry scenario. In the Zambezi river basin, hydropower falls by 10% by 2030, and by 35% by 2050 under the driest scenario (Strzepek et al 2012). Lower generation is *likely* in the upstream powerstations of the Zambezi basin and increases are *likely* downstream (Fant *et al.*, 2012).

10.3.5. Inland Navigation

See 10.4.4.

10.3.6. Irrigation

Climate change impacts on the economics of irrigation reflect the anticipated change in temperature, precipitation, and agricultural demand and practices. These narrowly focused reports do not address the broader issues of food production (covered in Chapter 7), nor economy wide impacts (Chapter 19). For example, by 2080, the global annual costs of additional irrigation water withdrawals for currently existing irrigated land are estimated at $24-27 billion (Fischer et al 2007). The global cost of improved irrigation efficiency to maintain yields is $1.5-2.0 billion dollar per year in developing countries in 2050 for the A2 scenario. (Nelson *et al.*, 2009) find that adaptation for Ethiopia to maintain agricultural production in Ethiopia would be best achieved by soil water management from increased irrigated and drained areas, improved irrigation efficiency and research related to on-farm practices. Adaptation costs range from $68 million per year for the dry scenario dominated by irrigation, to $71 million per year under the wet scenario dominated by drainage (Strzepek et al. 2010).

10.3.7. Nature Conservation

Climate change is expected to worsen many forms of water pollution, including the load of sediments, nutrients, dissolved organic carbon, pathogens, pesticides, and salt, as well as thermal pollution, increased precipitation intensity, and low flow periods (Kundzewicz *et al.*, 2007). Future water demands for nature conservation will be different than today’s (see Chapter 4). There is no published assessment of the economic implications.

10.3.8. Recreation and Tourism

Tourism and recreation use substantial amounts of water but the implications of climate-change-induced changes in tourism and recreation on water demand have yet to be quantified. See Section 10.6.

10.3.9. Water Management and Allocation

Changes in water availability, demand and quality due to climate change would impact water management and allocation decisions. Traditionally, water managers and users have relied on historical experience when planning water supplies and distribution(Adger *et al.*, 2007; UNFCCC, 2007). Water has been allocated based on societies’ preferences. Under a changing climate, existing allocations may no longer be appropriate. Arndt et al 2012 examine the economy-wide implications of existing water allocations and alternative development paths and allocation to suggest climate-smart development strategies in Africa. Under stress situations, allocations of water for energy-generation and irrigation may have economy-wide welfare implications. Climate change impacts on undiscounted USA welfare over the 21st century range from plus $3 trillion for wet scenarios to minus $13 trillion under dry scenarios (Strzepek et al. 2013).

10.3.10. Summary

Economic impacts of climate change on water related economic sectors have been dominated by incurred economic losses, including flooding, scarcity and cross sectoral induced impacts. Flooding and drought can have major economic costs, in term of impacts (capital destruction, disruption) whereas estimates of adaptation costs (construction, defensive investment) remain relatively modest. Water scarcity and competition for water, driven by institutional, economic or social factors, may mean that water assumed to be available for a sector is not.

10.4. Transport

The impact of climate change on transport has received qualitative, but limited quantitative, focus in the published literature. The impact depends greatly on the climatic zone the infrastructure is in and how climate change will be manifest. There are three major zones:

Geographic Zone	Vulnerabilities to Changes in Climate
Freezing/Frost Zone	Permafrost, freeze-thaw cycles, precipitation intensity
Temperate Zone	Change in Precipitation intensity, maximum daily precipitation
Tropical Zone	Change in Precipitation intensity, maximum daily precipitation

As detailed below, several studies have actively explored the potential impacts of climate change on the transport sector, focusing on overall impacts such as impacts on transportation safety or disruptions of transportation service. Quantitative, economic analyses of the impact on physical infrastructure include (Larsen *et al.*, 2008; Chinowsky *et al.*, 2010; Hunt and Watkiss, 2010; Chinowsky *et al.*, 2011) and on wider economic implications (Arndt, 2012).

10.4.1. Roads

Studies on the direct effects of climate change on road networks are primarily focused on qualitative predictions and surveys concerning road impacts on road durability (TRB, 2008b; Koetse and Rietveld, 2009) (Eisenack et al 2012 ; Ryley and Chapman 2012) with some studies of the quantitative effects (MacArthur et al 2012; Nemry and Nemirel 2012). Chapter 8 addresses the indirect effects of climate change on roads in the areas of congestion and safety.

Paved road degradation is directly related to weather stressors that can lead to softening of the pavement as temperatures exceed design thresholds (Lavin, 2003) and an increase in the number of freeze-thaw cycles impacts both the base and pavement surface (FHWA, 2006). The melting of permafrost in northern climates as well as increased precipitation and flooding threaten the integrity of road base and sub-bases. Drainage presents a specific problem for urban areas that experience rainfall above their built capacity and will impact design standards and costs for urban transport (CCTF, 2008; Hunt and Watkiss, 2010; Lemmen and Warren, 2010). Increased fire danger from droughts could also pose a threat to roads.

Unpaved roads are vulnerable to a number of climate-based factors especially to increasingly intense precipitation, leading to wash out and disruption of service. In cold climates, temporary winter roads are susceptible to warming and associated lower connectivity of rural areas and reduced economic activity in Northern climates (Mills and Andrey, 2002). Warming could imply that ice roads can no longer be maintained.

10.4.2. Rail

Rail beds are susceptible to increases in precipitation, sea level rise, extreme events and incidence of freeze-thaw cycles (Nemry and Nemirel 2012). In Northern climates, the melting of permafrost (URS, 2010) may lead to ground settlement, undermining stability (Larsen *et al.*, 2008). Increased temperatures pose a threat to rail through thermal expansion. In urban areas, increased temperatures pose a threat to underground transport systems that will see a burden on increased need for cooling systems (Hunt and Watkiss, 2010). For example, £178 million has been allocated to finding a workable solution for increasing the capacity of London’s underground cooling system (Arkell and Darch, 2006).

10.4.3. Pipeline

Increases in precipitation and temperature affect pipelines through scouring of base areas and unearthing of buried pipelines, compromised stability of bases built on permafrost, and increases in necessary maintenance (TRB, 2008a;

URS, 2010). Temperature increase can result in thermal expansion of the pipelines, causing cracking at material connection points. There has been no economic assessment of the impacts.

10.4.4. Shipping

Impacts of inland navigation vary widely due to projected rise or fall in water levels. Overall, the effects on inland navigation are projected to be negative, and are region-specific.

Increased frequency of flood periods will stop ship traffic on the Rhine more often. Longer periods of low flow will also increase the average annual number of days during which inland navigation is hampered or stagnates due to limited load carrying capacity of the river. Current projects on channel improvements can only partly alleviate these problems (Middelkoop *et al.*, 2001a). Economic impact could be substantial given the value of navigation on the Rhine (Krekt et al., 2011). See Chapter 23 for more detail.

(Millerd, 2010) analyzes the economic impacts of lower water levels in the Great Lakes, with consequent reductions in vessel cargo capacities and increases in shipping costs. The lower water levels predicted as a result of a doubling of the atmospheric carbon dioxide could increase annual transportation costs by 29%. More moderate climate change could result in a 13 percent increase in annual shipping costs. The impacts vary between commodities and routes.

Warming is *very likely* to lead to increased ice-free navigation and longer shipping season, but *is very likely* also lead to lower water levels from reduced runoff (Lemmen and Warren, 2010). In cold regions, increased days of ice-free navigation and a longer shipping season could positively impact shipping and reduce transportation costs (TRB, 2008b; Koetse and Rietveld, 2009; UNCTAD, 2009; UNECE and UNCTAD, 2010).

Ports will be affected by higher temperatures, sea level rise, increasingly severe storms, and increased precipitation (Becker *et al.*, 2011) (Nursey-Bray and Miller 2012; Nicholls, R. J. et al.,2008). Over $3 trillion in assets in 136 of the world's largest port cities are vulnerable to weather events (Potter *et al.*, 2008; UNCTAD, 2009; UNECE and UNCTAD, 2010).

Increased storminess in certain routes may raise cost of shipping through additional safety measures or longer routes that are less storm prone (UNCTAD, 2009; UNECE and UNCTAD, 2010). Transport costs would increase or new routes sought if storms disrupt supply chains by destroying port infrastructure connecting road or rail (Becker *et al.*, 2011). Increased storminess may also affect passage through lock systems (Potter *et al.*, 2008; UNCTAD, 2009). Increased storminess may increase maintenance costs for ships and ports and result in more frequent weather-related delays.

10.4.5. Air

Hotter air is less dense. In summer months, especially at airports located at high altitudes, this will result in limitations for freight capacity, safety, and weather-related delays, unless runways are lengthened (TRB, 2008a; Pejovic *et al.*, 2009). (Chapman, 2007) suggests that technological innovations will negate the challenges posed by extreme temperatures Increased storminess at airports, particularly those located in coastal regions, may increase the number of weather-related delays and cancellations (Pejovic *et al.*, 2009; Lemmen and Warren, 2010), with associated economic losses.

The impact of climate change on airport pavement is very similar to paved roads (DOT, 2002; Fortier *et al.*,). The effect of temperature on airports thus imposes a risk to the entire facility (Pejovic *et al.*, 2009) and related economic activity.

10.5. Other Primary and Secondary Economic Activities

This section assesses the impact of climate change on primary (agriculture, mining) and secondary economic activities (manufacturing, construction), unless they are discussed elsewhere in the chapter or the report.

10.5.1. Primary Economic Activities

Primary economic activities (e.g. agriculture, forestry, fishing, mining) are particularly sensitive to the consequences of climate change because of their immediate dependence on the natural environment. In some regions, these activities dominate the economy.

10.5.1.1. Crop and Animal Production

Chapter 7 assesses the impact of climate change on agriculture, including the effects on (international) markets for crops.

10.5.1.2. Forestry and Logging

Chapter 4 assesses the biophysical impact of climate change on forestry. Including adaptation in forest management, climate change would accelerate tree growth. This would reduce prices to the benefits of consumers all around the world. Low to mid latitude producers would benefit too as they switch to short-rotation plantations. Mid to high latitude producers would be hurt by lower prices while their productivity increases only modestly (Sohngen and Mendelsohn, 1997; Sohngen and Mendelsohn, 1998; Sohngen *et al.*, 2001); (Perez-Garcia *et al.*, 2002; Lee and Lyon, 2004; *Adaptation of Forests and People to Climate Change -- A Global Assessment Report.*2009). However, increased biomass prices may impact different forest based industries in different ways given their demand for renewable energy from the biomass sources (Moiseyev *et al.*, 2011).

10.5.1.3. Fisheries and Aquaculture

Chapter 4 assesses the impact of climate change on freshwater ecosystems, and Chapter 5, 6 and 30 on marine ecosystems. These assessments include the effects on commercially valuable fish stocks, but exclude the effects on markets. Adaptation and markets would substantially change the effect of climate change on fisheries (Link and Tol, 2009; Yazdi and Fashandi, 2010).

(Allison *et al.*, 2009), using an indicator based approach, analyzed the vulnerability of capture fishery of 132 economies. They find, incongruously, that the sign and size of climate-driven change for particular fish stocks and fisheries are uncertain but are *likely* to lead to either increased economic hardship or missed opportunities for development in countries that depend upon fisheries but lack the capacity to adapt. A major part of the gross turnover of nine key fish and cephalopod species in the Bay of Biscay remains potentially unaffected by climate change (Floc'h *et al.*, 2008). In contrast, Iberian-Atlantic sardine biomass and profitability declines due to climate change (Garza-Gil *et al.*, 2011). The economic impact of climate change on fisheries is dominated by the impact of management regime and market (Eide and Heen, 2002; McGoodwin, 2007; Eide, 2008; McIlgorm, 2010; Merino *et al.*, 2010).

Ocean acidification has a range of impacts on the biological systems (Doney *et al.*, 2009), but the studies on the economic impacts of ocean acidification are rare. (Brander *et al.*, 2012) estimate the economic impacts of ocean acidification on coral reefs under four IPCC marker scenarios using value transfer function approach and find that the annual economic impacts increase rapidly overtime, though it remains a small fraction of total income. Using a partial equilibrium model, (Narita *et al.*, 2012) estimate the economic impact of ocean acidification on shellfish, mollusks. By the turn of this century the cost of could be over $100 billion.

10.5.1.4. Mining and Quarrying

Climate change would affect exploration, extraction, production, and shipping in the mining and quarrying industry (Pearce *et al.*, 2011). An increase in climate-related hazards (such as forest fires, flooding, windstorm) affects the viability of mining operations and potentially increases operating, transportation, and decommissioning costs. Most infrastructure was built based on presumption of a stable climate, and is thus not adapted to climate change (Ford *et al.*, 2010; Ford *et al.*, 2011; Pearce *et al.*, 2011).

10.5.2. Secondary Economic Activities

10.5.2.1. Manufacturing

Climate change would impact manufacturing through three channels. First, climate change affects primary economic activities (see above), and this means that prices and qualities of inputs are different. Second, the production process is affected, or the quality of the product. The impact of climate change on energy demand is well understood (see 10.2). Using a biophysical model of the human body, (Kjellstrom *et al.*, 2009a) project labour productivity to fall, particularly of manual labour in humid climates. (Hübler *et al.*, 2008) uphold the finding with a German case study, and (Hsiang, 2010) corroborate it with a statistical analysis of weather data and labour productivity in the Caribbean for 1970-2006. Some manufacturing activity is location specific, perhaps because it is tied to an input or product market, and will thus have to cope with the current and future climate; other manufacturing has discretion over its location (and hence its climate). Third, climate change affects the demand for products. This is pronounced in manufactures that supply primary sectors (Kingwell and Farré, 2009) and construction material (see below). Unfortunately, there are only a few studies that quantify these effects (see Appendix A).

10.5.2.2. Construction and Housing

Climate and climate change affect construction in three ways. First, weather conditions are one of the key factors in construction delays and thus costs. Climate change would change the length of the building season. Additionally, precipitation affects the cost of construction through temporary flood protection (coffer) structures, slope stabilization management and dewatering of foundations. There are adaptation measures that may reduce some of the costs. (Apipattanavis *et al.*, 2010) show a reduction in the expected value of road construction delays and associated costs. Second, buildings and building materials are designed and selected to withstand a particular range of weather conditions. As climate changes, design standards will change too. Exterior building components including windows, roofing, and siding are all specified according to narrow environmental constraints. Climate change would introduce conditions that are outside the prescribed operating environment for many materials, resulting in increased failures of window seals, increased leaks in roofing materials, and reduced lifespan of timber or glass-based cladding materials. Similarly, the interior building systems that allow for proper airflow in a facility face significant issues with climate change. For example, the increases in temperature and precipitation will lead to increased humidity as well as indoor temperatures. This requires increased airflow in facilities such as hospitals, schools, and office buildings, that is, upgrades to air conditioning and fan units and perhaps further renovations that may be significant in scope and cost. Third, a change in the pattern of natural disasters would imply a change in the demand for rebuilding and repair. Unfortunately, these impacts have yet to be quantified.

10.6. Recreation and Tourism

Recreation and tourism is one of the largest sectors of the world economy. In 2011, it accounted for 9% of global expenditure, and employed 260 million people (WTTC, 2011). Supply of tourism services is the dominant activity in many regional economies.

Recreation and tourism encompass many activities, some of which are more sensitive to weather and climate than others: compare sunbathing to angling, gambling, business seminars, family visits, and pilgrimage. Climate change would affect the place, time and nature of these activities.

There is a large literature on the impact of climate change on tourism (Gössling *et al.*, 2012; Scott *et al.*, 2012a; Pang *et al.*, 2013). Some studies focus on the changes in the behavior of tourists, that is, the demand for recreation and tourism services (see 10.6.1). Other studies look at the implications for tourist operators and destinations, that is, the supply of recreation and tourism services (see 10.6.2). A few studies consider the interactions between changes in supply and demand (see 10.6.3).

10.6.1. Recreation and Tourism Demand

Conventionally, recreation does not involve an overnight stay whereas tourism does. That implies that recreation, unlike tourism, is done close to home (while leisure is done at home). Whereas tourists, to a degree, chose the climate of their holidays, recreationists do not (although climate is a consideration in the choice where to live). Tourists would adapt to climate change by changing the location, timing and activities of their holidays; recreationists would adapt only timing and activities (Smith, 1990).

10.6.1.1. Recreation

There has been no research on systematic differences of recreational behaviour due to differences in climate at large spatial scales. The impact of climate change on recreation is therefore largely unknown. The economic impact is probably limited, as people are more *likely* to change the composition rather than the level of their time and money spent on recreation. For instance, (Shaw and Loomis, 2008) argue that climate change would increase boating, golfing and beach recreation at the expense of skiing.

There are case studies of the impact of climate change on recreation. (Buckley and Foushee, 2012) find that a trend toward earlier visits to US national parks between 1979 and 2008. They argue this is due to climate change, but do not rigorously test this hypothesis nor control for other explanations. (Dempson *et al.*, 2001) note that the salmon fishery in Newfoundland is closed during hot weather and low water levels. (Ahn *et al.*, 2000) study the impact of climate change on recreational trout fishing in the Southern Appalachian Mountains, and (Whitehead *et al.*, 2009) the effect of sea level rise on sea shore fishing in North Carolina, finding a substantial decrease in the recreational value of these activities. (Daugherty *et al.*, 2011) conclude that climate change will make it more difficult to guarantee adequate water levels for boating and angling in artificial reservoirs. (Pouta *et al.*, 2009) project a reduction in cross-country skiing in Finland, particularly among women, the lower classes, and urban dwellers. (Shih *et al.*, 2009) find that weather affects the demand for ski lift trips. One could expect people to adopt other ways of enjoying themselves but such alternatives were excluded from these studies. There are positive effects too. (Richardson and Loomis, 2005) find that climate change would make trips to the Rocky Mountain National Park more enjoyable. (Scott and Jones, 2006; Scott and Jones, 2007) foresee an increase in golf in Canada due to climate change, (Kulshreshtha, 2011) sees positive impacts on Canadian recreation in general, and (Coombes *et al.*, 2009) predict an increase in beach tourism in East Anglia. (Graff Zivin and Neidell, 2010) find that people recreate indoors when the weather is inclement. (Scott *et al.*, 2007) estimate the relationship between visitors to Waterton Lakes National Park and *weather* variables for eight years of monthly observations; and use this to project an increase in visitor numbers due to *climate change*. A survey among current visitors indicates that a deterioration of the quality of nature would reduce visitor numbers.

10.6.1.2. Tourism

Climate (Becken and Hay, 2007; WTO and UNEP, 2008) and weather (Rosselló-Nadal *et al.*, 2010; Álvarez-Díaz and Rosselló-Nadal, 2010; Rossello, 2011; Førland *et al.*, 2012; Day *et al.*, 2013; Falk, 2013) are important factors in tourist destination choice, and the tourist sector is susceptible to extreme weather (Forster *et al.*, 2012; Forster *et* *al.*, 2012; Hamzah *et al.*, 2012; Tsai *et al.*, 2012). (Eijgelaar *et al.*, 2010), for instance, argues that so-called “last chance tourism” is a strong pull for tourists to visit Antarctica to admire the glaciers while they still can. (Farbotko, 2010; Prideaux and Mcnamara, 2012) use a similar mechanism to explain the rise in popularity of Tuvalu as a destination choice, but (Huebner, 2012) find no impact of future climate change on current travel choices. (Taylor and Ortiz, 2009) show that domestic tourists in the UK often respond to past weather. The hot summer of 2003 had a positive impact on revenues of the tourist sector. (Denstadli *et al.*,) find that tourists in the Arctic do not object to the weather in the Arctic. (Gössling *et al.*, 2006) reaches the same conclusion for tourists on Zanzibar, and (Moreno, 2010) for tourists in the Mediterranean.

(Maddison, 2001) estimates a statistical model of the holiday destinations of British tourists, (Lise and Tol, 2002) for Dutch tourists and (Bigano *et al.*, 2006) for international tourists from 45 countries; these models control for as other variables as possible. Tourists have a clear preference for the climate that is currently found in Southern France, Northern Italy and Northern Spain. People from hot climates care more about the climate in which they spend their holidays than people from cool climates. (Bujosa and Rosselló, 2012) study destination choice within Spain, and find the climate change would induce a northward shift.

However, whereas (Bigano *et al.*, 2006) find regularity in revealed preferences, (Scott *et al.*, 2008b) find pronounced differences in stated preferences between types of people. The impact of climate change on tourism demand may be more complicated than suggest by the econometric analyses reviewed above (Gössling and Hall, 2006).

(Hamilton *et al.*, 2005a; Hamilton *et al.*, 2005b; Bigano *et al.*, 2007) use the above econometric analyses to construct a simulation model of domestic and international tourism. (Hamilton and Tol, 2007) downscale the national results of these studies to the regions of selected countries. The advantage of such a model is that it considers the simultaneous change in the attractiveness of all potential holiday destinations (Dawson and Scott, 2013). The disadvantage is its stylized representation of the effect of climate on destination choice. Two main findings emerge. First, climate change would drive tourists to higher latitudes and altitudes. International tourist arrivals would fall, relative to the scenario without warming, in hotter countries, and rise in colder countries. Tourists from Northwestern Europe, the main origin worldwide of international travelers at present, would be more inclined to spend the holiday in their home country, so that the total number of international tourists falls. Second, the impact of climate change is dominated by the impact of population growth and, particularly, economic growth. In the worst affected countries, climate change slows down, but nowhere reverses, growth in the tourism sector.

10.6.2. Recreation and Tourism Supply

There are a number of biometeorological studies of the impact of climate change on tourism. (Yu *et al.*, 2009a) find that Alaska has become more attractive over the last 50 years, and Florida less attractive to tourists. (Yu *et al.*, 2009b) conclude that the climate for sightseeing has improved in Alaska, while the climate for skiing has deteriorated. (Scott *et al.*, 2004) show that climate change would make Mexico less attractive to tourists, and Canada more attractive. Florida and Arizona would lose market share in US tourism. (Perry, 2006) speculates that the hot summer of 2003 had a negative impact on tourism in the Mediterranean. (Matzarakis *et al.*, 2010) construct a composite index of temperature, humidity, wind speed and cloud cover, and use this to map tourism potential. (Lin and Matzarakis, 2008; Lin and Matzarakis, 2011) apply the index to Taiwan and Eastern China. (Endler and Matzarakis, 2010a; Endler and Matzarakis, 2010b; Endler and Matzarakis, 2011) use an index to study the Black Forest in Germany in detail, highlighting the differences between summer and winter tourism, and between high and low altitudes; the latter aspect is thoroughly investigated by (Endler *et al.*, 2010). (Zaninović and Matzarakis, 2009; Matzarakis and Endler, 2010) use this method to study Freiburg and Hvar. (Matzarakis *et al.*, 2007) project this potential into the future, finding that the Mediterranean will probably become less attractive to tourists. (Amelung and Viner, 2006; Hein *et al.*, 2009; Perch-Nielsen *et al.*, 2009; Giannakopoulos *et al.*, 2011; Amelung and Moreno, 2012; Amengual *et al.*, 2012) reach the same conclusion, but also point out that Mediterranean tourism may shift from summer to the other seasons. (Giannakopoulos *et al.*, 2011) notes that coastal areas in Greece may be affected more than inland areas because, although temperature would be lower, humidity would be higher. (Moreno and Amelung, 2009), on the other hand, conclude that climate change will not have a major impact (before 2050) on beach tourism in the Mediterranean because sunbathers like it hot (Moreno, 2010; Rutty and Scott, 2010). (Amelung *et al.*, 2007) use a weather index for a global study of the impact of climate change on tourism, finding shifts from equator to pole, summer to spring and autumn, and low to high altitudes. (Perch-Nielsen, 2010) combines a meteorological indicator of exposure with indicators of sensitivity and adaptive capacity. She uses this to rank the vulnerability of beach tourism in 51 countries. India stands out as the most vulnerable, and Cyprus as the least vulnerable.

The main criticism of most biometeorological studies is that the predicted gradients and changes in tourism attractiveness have rarely been tested to observations of tourist behaviour. (De Freitas *et al.*, 2008) validate their proposed meteorological index to survey data. (Moreno *et al.*, 2008) and (Ibarra, 2011) use video of beach occupancy to test meteorological indices for beach tourism. (Gómez-Martín, 2006) tests meteorological indices against visitor numbers and occupancy rates. All four studies find that weather and climate affects tourists, but in a different matter than typically assumed by biometeorologists.

Studies on the supply side often focus on ski tourism. (Abegg and Elsasser, 1996) is one of the earliest papers. Warming of would raise the altitude of snow-reliable resorts, and fewer resorts would be snow-reliable (Hendrikx *et al.*, 2012; Steger *et al.*, 2012). (Elsasser and Bürki, 2002) argue that artificial snow-making cannot fully offset the loss in natural snowfall in the Swiss Alps. (Schmidt *et al.*, 2012) show that snow-making is less successful in lower areas, although that is the current strategy of operators in Austria (Wolfsegger *et al.*, 2008; Morrison and Pickering, 2012). (Hamilton *et al.*, 2007) highlight the importance of “backyard snow” to induce potential skiers to visit ski slopes. (Pickering *et al.*, 2010) find that skiers in Australia prefer natural snow over artificial snow. From a series of interviews, (Hill *et al.*, 2010) find that tourist operators in the Swiss Alps seek to maintain the status quo through adaptation, rather than search for viable alternatives to ski tourism; and argue that better coordination is needed for adaptation to be successful. (Scott and McBoyle, 2007) highlight that there are many options to adapt to a loss of snow for skiing. (Hoffmann *et al.*, 2009) use a survey of ski lift operators in the Swiss Alps. They find that the need for adaptation exceeds the ability to adapt and that adaptation is more prevalent on higher slopes (which are less vulnerable). (Scott *et al.*, 2006) study the impact of climate change on ski areas in eastern North America. Even with snowmaking, climate change could be an existential threat to 3 of the 6 ski areas by 2050; and climate change would lead to a contraction in each area in each scenario. (Dawson *et al.*, 2009) use past analogues to study the impact of future climate change on ski tourism in the Northeastern USA. They find that small and very large resorts will be hit hardest, and low-lying ones. (Scott *et al.*, 2008a) find that snowmobiling would have disappeared from the Northeastern USA by the end of the 21st century. (Mcboyle *et al.*, 2007) find the same for the Canadian lowlands. (Matzarakis *et al.*, 2012)Artificial snowmaking would halt the decline of ski resorts, but water scarcity and the costs of snowmaking would be increasingly large problems. (Scott *et al.*, 2003) reach the same conclusion for southern Ontario, (Scott *et al.*, 2007) for Quebec, (Hendrikx and Hreinsson, 2012) for New Zealand, (Steiger and Mayer, 2008) for Tyrol, and (Pons-Pons *et al.*, 2012) for Andorra. (Bicknell and Mcmanus, 2006) study adaptation for ski resorts in Southeastern Australia. They note that resorts may continue to be economically viable in the absence of snow by focusing on alternative activities. (Pickering and Buckley, 2010) note that artificial snow-making may be infeasible and uneconomic at the scale required to offset the loss of natural snow in Australia, and argue for a reorientation towards summer tourism and residential property development. (Moen and Fredman, 2007) find that alpine ski resorts in Sweden would become economically unviable, and that alternative livelihoods need to be developed. (Tervo, 2008) finds that the shortening of the Finnish ski season would be too limited to affect the economic viability of tourist operators, but (Landauer *et al.*, 2012) find that Finnish ski operators would find it difficult to convince their clients of the need to adapt. (Serquet and Rebetez, 2011) find that the Swiss Alps attract more tourists during hot summers, and argue that climate change would structurally improve the mountains as a summer tourism destination. (Matzarakis *et al.*, 2012) also argue that a proper assessment considers all seasons, using Austria as an example. (Bourdeau, 2009) argue along the same lines for the French Alps, stressing the importance of non-tourism alternatives as a source of economic development. (Steiger, 2010) finds that stakeholders in Tyrol think that gains in summer would not fully offset losses in winter. (Potocka and Zajadacz, 2009) argue that prudent management supplies tourism services suitable for all weather. (Steiger, 2012) finds that, in the first half of this century, demographic trends are more important to skiing in Austria than climate change. (Hopkins *et al.*, 2012) also argue that other factors dominate the impact of climate change.

Other studies consider beach tourism. (Scott *et al.*, 2012b) highlight the vulnerability of coastal tourism facilities to sea level rise. (Hamilton, 2007) finds that tourists are averse to artificial coastlines, so that hard protection measures against sea level rise would reduce the attractiveness of an area. (Raymond and Brown, 2011) survey tourists on the Southern Fleurieu Peninsula. They conclude that tourists who are there for relaxation worry about climate change, particularly sea level rise, while tourists who are there to enjoy nature (inland) do not share that concern. (Becken, 2005) finds that tourist operators have adapted to weather events, and argues that this helps them to adapt to climate change. (Belle and Bramwell, 2005) find that tourist operators on Barbados are averse to public adaptation policies. (Uyarra *et al.*, 2005) find that tourists on Barbados would consider holidaying elsewhere if there is severe beach erosion. (Buzinde *et al.*, 2010a; Buzinde *et al.*, 2010b) find that there is a discrepancy between the marketing of destinations as pristine and the observations of tourists, at least for Mexican beach resorts subject to erosion. They conclude that tourists have a mixed response to environmental change, contrary to the officials' view that tourists respond negatively. (Jopp *et al.*, 2013) find that an increase in tourism in the shoulder season may offset losses in the peak season in Victoria.

Some studies focus on nature tourism. (Wall, 1998) notes the impact of climate change on water-based tourism, on the coast through sea level rise and inland through drought. (Cavan *et al.*, 2006) find that climate change may have a negative effect on the visitor economy of the Scottish uplands as natural beauty deteriorates through increased wild fires. (Saarinen and Tervo, 2006) interviewed nature-based tourism operators in Finland, and found that about half of them do not believe that climate change is real, and that few have considered adaptation options. (Nyaupane and Chhetri, 2009) argue that climate change would increase weather hazards in the Himalayas and that this would endanger tourists. (Uyarra *et al.*, 2005) find that tourists on Bonaire would not return if coral was bleached. (Hall, 2006) finds that small tourist operators in New Zealand do not give high priority to climate change, unless they were personally affected by extreme weather in recent times. The interviewed operators generally think that adaptation is a sufficient response to climate change for the tourism sector. (Klint *et al.*, 2012) find that tourist operators in Vanuatu give low priority to adaptation to climate change and (Jiang *et al.*, 2012) find Fiji poorly prepared. (Saarinen *et al.*, 2012) find that tourist operators in Botswana think that climate change would not affect them. (Wang *et al.*, 2010) note that glacier tourism is particularly vulnerable to climate change, highlighting the Baishiu Glacier in China.

While the case studies reviewed above provide rich detail, it is hard to draw overarching conclusions. A few studies consider all aspects of the impact of climate change for particular countries or regions. (Ren Guoyu, 1996) shows that domestic tourism in China would shift northwards, that sea level rise would damage some tourist facilities, and that the overall impact of climate change on China's tourist sector would be negative. (Harrison *et al.*, 1999) conclude that climate change would make Scotland less attractive to tourists in winter but more attractive in summer. (Ceron and Dubois, 2005) assess the impact of climate change on tourism in France. They argue that the French Riviera may benefit because it is slightly cooler than the competing coastal resorts in Italy and Spain. The Atlantic Coast, although warming, would not become more attractive because of increased rainfall. It is not probable that the increase in summer tourism in the mountains would offset the decrease in winter tourism. (Jones *et al.*, 2006) study the impact of climate change on three festivals in Ottawa. They argue for heat wave preparedness for Canada Day, find that skating on natural ice may become impossible for Winterlude, and fret that the dates of the Tulip Festival may need to be shifted to reflect changing phenology. (Dawson and Scott, 2010) assess the impacts in the Great Lakes regions, finding reduced tourism potential in winter but increased opportunities in summer. (Turton *et al.*, 2010) conclude that tourist operators in Australia find the uncertainty about climate change too large for early investment in adaptation.

10.6.3. Market Impacts

There are only two papers that consider the economic impacts of rather stylized climate-change-induced changes in tourism supply and demand. Both studies use a computable general equilibrium model, assessing the effects on the tourism sector as well as all other markets. (Berrittella *et al.*, 2006a) consider the consumption pattern of tourists and their destination choice. They find that the economic impact is qualitatively the same as the impact on tourist flows (discussed above): Colder countries benefit from an expanded tourism sector, and warmer countries lose. They also find a drop in global welfare, because of the redistribution of tourism supply from warmer (and poorer) to colder (and richer) countries. (Bigano *et al.*, 2008a) extend the analysis with the implications of sea level rise. The impact on tourism is limited because coastal facilities used by tourists typically are sufficiently valuable to be protected against sea level rise. The study finds that the economic impacts on the tourism sector are reinforced by the economic impacts on the coastal zone; and that the welfare losses due to the impact of climate change on tourism are larger than the welfare losses due to sea level rise.

10.7. Insurance

10.7.1. Main Results of AR4 and SREX

More intense or frequent weather-related disaster would affect property insurance, which is growing with the economy everywhere (WG II, 7.4.2.2.4). Insurability can be preserved through risk-reducing measures. Adaptation to climate change can be incentivized through risk-commensurate insurance premiums. Improved risk management would further financial resilience (WG II, 7.4.2.2.4., 7.6.3). Insurance is linked to disaster risk reduction and climate change adaptation, because it enables recovery, reduces vulnerability and provides knowledge and incentives for reducing risk ((IPCC, 2012)).

10.7.2. Societal Role of Insurance Covering Weather Hazards

Insurance internalizes catastrophe risk costs prior to catastrophic events, reducing the economic impact of weather-related and other disasters to individuals and enterprises, thus stabilizing income and consumption, and decreasing societal vulnerability. Insurance is based on the law of large numbers: the larger the pool of uncorrelated and relatively small risks, the more accurately the average loss per policy can be predicted and charged accordingly, allowing for a lower premium than with a smaller pool. Besides spreading risk over a diversified insured population, insurance spreads risk over time. However, weather-related disasters such as floods simultaneously affect many, and thus violate the principle of uncorrelated risks. Consequently, large losses are much more *likely*, the loss variance is greater, and the tail risk is higher ((Kousky and Cooke, 2012)). If insurance coverage is to be maintained, insurers would need more risk capital to indemnify catastrophic losses and remain financially solvent. This coverage is purchased in the reinsurance and capital markets. The capital costs account for a substantial portion of premiums and the affordability and viability of weather insurance are subjects of ongoing research given future climate change ((Charpentier, 2008); (Maynard and Ranger, 2012); (Clarke and Grenham, 2012)).

Increasing volatility and burden of losses in many regions are expected to fundamentally impact on the industry, leading insurers to adapt their business to the changing risk ((Herweijer *et al.*, 2009); (Phelan *et al.*, 2011); (Mills, 2012); (Paudel, 2012)).

10.7.3. Observed and Projected Insured Losses from Weather Hazards

Direct and insured losses from weather-related disasters have increased substantially in recent decades both globally and regionally ((IPCC, 2012); (Bouwer *et al.*, 2007); (Swiss Re, 2012); (Munich Re., 2012); (Crompton and McAneney, 2008); (Gall *et al.*, 2011); (Smith and Katz, 2013)). Substantially fluctuating global insured weather-related losses in the period 1980-2008 increased by US$^{2008}1.4bn per year on average (Barthel and Neumayer, 2012). As a rule, insured loss figures are more accurate than direct economic loss estimates, because insurance procedures and payouts are regulated and monitored. Hence, estimates of direct overall losses are often derived from insurance losses ((Kron *et al.*, 2012); (Smith and Katz, 2013)). Economic growth, including greater concentrations of people and wealth in periled areas and rising insurance penetration, is the most important driver of the increase in losses.

Growth induced changes in past losses are removed by normalizing to current levels of destructible wealth. So far, there is only one study analyzing global normalized weather-related insured losses, but the period (1990-2008) is too short to infer any reliable trend (Barthel and Neumayer, 2012). A few studies focus on specific perils and regions, in particular Australia, USA and Europe. Trends were detected for the USA and Germany, but not for Australia and Spain (Table 10-4). Trends in normalized insured losses can be influenced not only by changing hazards but also by changing damage sensitivities, adaptive measures, different normalization, and changes in insurance ((Barthel and Neumayer, 2012); (Crompton and McAneney, 2008); (Bouwer, 2011); (IPCC, 2012)). Prevention measures such as flood control structures, or improved building standards over time, would offset an increase in hazard ((Kunreuther *et al.*, 2009)). The 2011 Mississippi flood resulted in US$4.6bn direct losses, but losses exceeding US$200bn were avoided by flood controls, according to the U.S. Army Corps of Engineers ((Kron and Steuer, 2012); DeHaan *et al.*, 2012). Given such confounding factors, it is challenging to estimate to what degree developments in losses convey a climate signal ((Kron, 2012); (IPCC, 2012)). Studies analyzing changes in climate variables and losses in parallel are still rare. The number of days that a regional insurer in southwest Germany sustains hail losses displays an upward trend since 1986, while meteorological severe storm indicators also show upward trends ((Kunz *et al.*, 2009)). Variability and mean level of thunderstorm-related insured losses in the USA in the period 1970-2009 have substantially increased, while meteorological thunderstorm forcing potential has risen in parallel ((Sander *et al.*, 2013)). (Corti *et al.*, 2009) found an increase in modeled and partly observed insured subsidence losses in France over the period 1961-2002, consistent with an increase in dryness in central and southern Europe ((IPCC, 2012)). The observed rise in US normalized insured flood losses (Barthel and Neumayer, 2012) may partly correspond to *likely* increased heavy precipitation events in parts of the USA ((IPCC, 2012) , AR5WG1-2.6.2.1), while the evidence for climate driven changes in river floods is non-compelling ((IPCC, 2012)). The recent upswing in hurricane hazard and losses appears to be connected to multi-decadal climate variability ((Lonfat *et al.*, 2007); AR5WG1-Box14.2; AR5WG1-14.7.3). Loss trends have not been conclusively attributed to anthropogenic climate change, and sientific attribution methods have not been applied.

[INSERT TABLE 10-4 HERE
Table 10-4: Observed normalized insured losses from weather hazards.]

Many (AO)GCM-based projections agree that extreme winter storm wind speeds fall in the Mediterranean and increase in west, central, and northern Europe. Loss ratios, i.e. insured loss divided by insured value, follow the same pattern (e.g., (Schwierz *et al.*, 2010); (Donat *et al.*, 2011); (Pinto *et al.*, 2012); AR5WG1-Box14.3) (Table 10-5). Return periods per loss level are projected to shorten in large parts of Europe, indicating more frequent high losses (e.g., (Pinto *et al.*, 2012)) (Table 10-5). Projected overall losses and fatalities develop accordingly ((IPCC, 2012); (Narita *et al.*, 2010)). Across three modeling approaches calibrated to German insurance data, the 25-year loss is projected to change by –10% to +18% (2011-2040), +5% to +41% (2041-2070), and +45% to +58% (2071-2100) against 1971-2000, keeping exposures and damage sensitivities constant (A1B, (Held *et al.*, planned 2013)).

[INSERT TABLE 10-5 HERE
Table 10-5: Climate change projections of insured losses and/or insurance prices.]

Direct losses and fatalities from flooding will increase with climate change in many locations in the absence of adequate adaptation ((IPCC, 2012); AR5WG1-12.4.5.5; 11.3.2.5.2). Mean annual insured heavy rainfall and flood losses in the UK, the Netherlands, southern Norway and the Canadian province of Ontario were projected to rise with climate change; for Germany an increase of more than 90% in insured river inundation losses in the period 2041-2070 relative to the late 20th century was projected, keeping exposures and sensitivities constant ((Hattermann *et al.*, planned 2013)) (Table 10-5).

Direct losses and fatalities from tropical cyclones will increase with exposure and may increase with the frequency of very intense cyclones in some basins ((IPCC, 2012); AR5WG1-Box14.3; (Peduzzi *et al.*, 2012)). Studies for the North Atlantic project a climate-driven loss increase ((Pielke, 2007); (Emanuel, 2011)). (Ranger and Niehoerster, 2012), (Kunreuther *et al.*, 2012), and (Raible *et al.*, 2012) found insured losses change in opposite directions across a range of dynamical and statistical model projections. Insured typhoon-related property losses in China are projected to increase ((Dailey *et al.*, 2009)). Averaged across four GCMs, (Mendelsohn *et al.*, 2012) project rising climate driven direct losses for the coasts of Central America, the Caribbean, North America, and East Asia. (Narita *et al.*, 2009) report an increase in damages and fatalities in all parts of the world.

Hailstorm insurance losses in the Netherlands ((Botzen *et al.*, 2010b)) and Germany ((Gerstengarbe *et al.*, 2013)) are projected to increase. Paddy rice insurance payouts are projected to decrease ((Iizumi *et al.*, 2008)) (Table 10-5).

Rising insured wealth will increase both losses and premium income, not necessarily altering the ratio of both, indicating impact. Such automatic compensation is not effective for external drivers of loss, such as changing hazard properties. Hence, projection studies using ratios of losses to premiums or sums insured (while assuming constant insured property) can be justified as an approximation of the climate change impact (e.g., (Donat *et al.*, 2011)). Consequently, future economic growth is rarely projected ((Aerts and Botzen, 2011)).

10.7.4. Supply-Side Challenges and Sensitivities

10.7.4.1. High-Income Countries

The provision of weather hazard insurance is contingent on an insurer's ability to find a balance between affordability of the premiums and costs that have to be covered by the revenue. On the cost side, the expected level of losses, expenses for risk assessment, product development, marketing, operating, and claims processing are included. Moreover, the revenue must provide a return on shareholders' equity and allow for the purchase of external capital if large losses are incurred ((Charpentier, 2008); (Kunreuther *et al.*, 2009)).

The balance between affordability and profitability is sensitive to climate change. Increases in large weather-related losses may corrode an insurer's solvency if it fails to reflect the changes in its risk management, or is hampered in doing so by price regulation, as was the case with the upswing in Atlantic hurricane activity in the USA since the mid-1990s ((Grace and Klein, 2009)). Additionally, misguided incentives for development in hazard-prone areas, as with the US National Flood Insurance Program ((Kousky and Kunreuther, 2010); (Michel-Kerjan, 2010); (GAO, 2011)), can aggravate the situation (Table 10-6).

[INSERT TABLE 10-6 HERE
Table 10-6: Supply-side challenges and sensitivities.]

The additional uncertainty induced by climate change translates into a need for more risk capital ((Charpentier, 2008); (Kunreuther *et al.*, 2009); (Grace and Klein, 2009)). This raises insurance premiums and affects the economy (Table 10-6). Health and life insurance are also affected through the health impacts of climate change ((Hecht, 2008); (Leurig, 2011)). Liability insurance, too, may be susceptible to climate change. So far, no damages have been awarded for greenhouse gas emissions as such, but litigation where damages are sought is pending ((Mills, 2009); (Heintz *et al.*, 2009); (Patton, 2011)). A decision by the Supreme Court of Virginia in April 2012 denied defense costs under the specific liability insurance policy of an utility company (Supreme Court of Virginia, U.S.A., 2012)) (Table 10-6).

10.7.4.2. Middle- and Low-Income Countries

Middle- and low-income countries account for a small share of worldwide non-life insurance: 16% of premiums in 2011 ((Swiss Re, 2013b)). In high-income countries some 40% of direct natural disaster losses have been covered by insurance since 1980, about 4% in middle-income countries and less than 1% in low-income countries ((Wirtz *et al.*, planned 2013); (IPCC, 2012)). For instance, only about 1% of direct overall losses in the 2010 floods in Pakistan were insured ((Munich Re., 2011)).

The small share of insurance in risk financing is not deemed economically prudent, because other options, such as external credit or donor assistance, can be unreliable and late. This leaves a financial gap in the months immediately following the event, often exacerbated by overstretched public finances. Pre-disaster financing instruments such as insurance or trigger-based risk-transfer products are a better means of providing prompt liquidity for households, businesses, and governments ((Ghesquiere and Mahul, 2007); (Linnerooth-Bayer *et al.*, 2009); (IPCC, 2012)). These may become more important if disaster incidence increases with climate change ((IPCC, 2012); (Collier *et al.*, 2009); (Hochrainer *et al.*, 2010)).

It is challenging to upscale catastrophe insurance because of low business volumes, high transaction costs, and high reinsurance premiums following large disasters. Small-scale insurance schemes in middle- and low-income countries may find it difficult to obtain sufficient risk capital ((Cummins and Mahul, 2009); (Mahul and Stutley, 2010)).

Microinsurance schemes, keeping transaction costs at the lowest operable level, mainly provide health and life cover to households and small enterprises in low-income markets. Supply of property insurance suffers from correlated weather risks, although weather-related agricultural damages are covered. Such weather coverage is growing, typically with government and NGO assistance or cross-subsidies from local insurers ((Linnerooth-Bayer and Mechler, 2011); (Qureshi and Reinhard, 2011)). These schemes may be particularly sensitive to a rise in disaster risk due to climate change ((Collier *et al.*, 2009); (Leblois and Quirion, 2011); (Clarke and Grenham, 2012)).

Adverse selection is another challenge: clients do not always disclose their high risk, e.g. a floodplain site, to the insurer so as to benefit from lower rates. Lower-risk participants are charged too high premiums and leave the scheme, thus increasing overall risk. In low-income countries, where data to establish homogenous risk groups are not available, this can cause disaster insurance markets to fail. Moral hazard is another issue, where the insured adopt more risky behavior than anticipated by the insurer, particularly in the absence of proper monitoring (e.g., (Barnett *et al.*, 2008); (Mahul and Stutley, 2010)).

10.7.5. Products and Systems Responding to Changes in Weather Risks

10.7.5.1. High-Income Countries

A rise in weather-related disaster risk may drive the need for more risk-based capital to cover the losses. There are several options that sustain insurability. Reducing vulnerability often makes sense even if expected climate change impacts will not materialize. Theoretically, risk-based premiums incentivize policyholders to reduce their vulnerability ((IPCC, 2012); (Hecht, 2008); (Kunreuther *et al.*, 2009)) (Table 10-7). Premium discounts for loss-prevention can further promote this ((Ward *et al.*, 2008); (Kunreuther *et al.*, 2009)) (Table 10-7). Moral hazard can be reduced by involving the policyholder to some extent in the payment of losses (deductibles, upper limits of insurance coverage: (Botzen and van den Bergh, 2009); (Botzen *et al.*, 2009)). Collaborative efforts of insurers and governments on damage prevention decrease risk ((Ward *et al.*, 2008); (Reinhold *et al.*, 2012)). For example, new building standards in Florida reduced mean damage per house by 42% in the period 1996-2004 relative to pre-1996 ((Kunreuther *et al.*, 2009)). Risk-based premiums are often hampered by price regulation, subsidies, competitive pressures, bundling of perils in one policy, and availability of data ((Maynard and Ranger, 2012)).

[INSERT TABLE 10-7 HERE
Table 10-7: Products and systems responding to changes in weather risks.]

Most commercial risk-assessment models only incipiently factor in changes in weather hazards, mainly to reflect higher hurricane frequencies ((Seo and Mahul, 2009)), assuming unchanging conditions for other weather hazards. Ignoring changing hazard conditions results in biased estimates of expected loss, loss variability and risk capital requirements ((Lonfat *et al.*, 2007); (Charpentier, 2008); (Watson and Johnson, 2008); (Herweijer *et al.*, 2009); 10.7.3). Other confounding factors, e.g. systemic economic impact, in recent large losses have been addressed (e.g., (Muir-Wood and Grossi, 2008)) (Table 10-7). Geospatial risk-assessment tools, e.g. flood-recurrence zoning with premium differentiation, counteract adverse selection ((Kunreuther *et al.*, 2009); (Mahul and Stutley, 2010)). Some insurers have offered weather alert systems and seasonal agricultural planning systems to clients (e.g., (Niesing, 2004); (*AgroClima. Informática Avanzada SA de CV.*2013)). Credit rating agencies and Solvency II insurance regulation in Europe contribute to enhanced disaster resilience ((Michel-Kerjan and Morlaye, 2008); (Kunreuther *et al.*, 2009); (Grace and Klein, 2009)). Insurers and researchers have projected climate change driven losses to allow for adaptation of the industry (e.g., (Held *et al.*, planned 2013); (Kunreuther *et al.*, 2012); 10.7.3). Due to its short-term contracts the insurance sector is better adaptable than others ((Botzen *et al.*, 2010a)).

Reinsurers are key to the supply of disaster risk capital. They operate globally to diversify the regional risks of hurricanes and other disasters. Access to reinsurance enhances risk diversification of insurers. Periodic shortages in reinsurance capacity following major disasters have moderated over the last two decades because of easier new capital inflow ((Cummins and Mahul, 2009); (IPCC, 2012)).

Global diversification potential of large losses has fallen over recent decades because of increasing dependence between major insurance markets. For instance, the Thailand floods of 2011 disrupt industrial hubs and global supply chains ((Courbage *et al.*, 2012)).This process may continue with climate change ((Sherement and Lucas, 2009); (Kousky and Cooke, 2012)). However, global diversification potential can be increased by developing insurance markets in middle- and low income countries ((Cummins and Mahul, 2009)).

Very large loss events, say in excess of US$ 100bn, may make additional capacity desirable. These disasters can be diversified in the financial securitization market ((IPCC, 2012)). Natural catastrophe risks are not correlated with capital market risks and hence are attractive to institutional investors. For instance, a catastrophe bond assures the investor above-market returns as long as a parametric index (e.g., wind-based) does not exceed a threshold, but pays the insurer’s loss otherwise. The catastrophe bond market reached critical mass after the hurricanes of 2004 and 2005, with some US$ 11bn of risk capital in effect by June 2011 ((Cummins, 2012); (Cummins and Weiss, 2009); (Michel-Kerjan and Morlaye, 2008); (Kunreuther and Michel-Kerjan, 2009)) (Table 10-7).

10.7.5.2. Middle- and Low-Income Countries

Index-based weather insurance is considered well-suited to the agricultural sector in developing countries (e.g., (Collier *et al.*, 2009); (IPCC, 2012)). Payouts depend on a physical trigger, e.g. cumulative rainfall at a nearby weather station, thus avoiding costly loss assessments. Moral hazard and adverse selection are removed ((Barnett *et al.*, 2008)). Risk-based premiums encourage adaptive responses ((Mahul and Stutley, 2010)) (Table 10-7). Basis risk, where losses occur but no payout is triggered, provokes distrust. Misunderstandings and scaling up of pilots pose further difficulties ((Patt *et al.*, 2010); (Leblois and Quirion, 2011); (Clarke and Grenham, 2012)). Suggested improvements include area-yield indices and coverage at aggregate level to reduce basis risk, and a cooperative architecture ((Clarke and Grenham, 2012); (Biener and Eling, 2012)) (Table 10-7). For both indemnity-based and index-based trigger concepts application prospects are identified, depending on the insured’s characteristics and the market setting (Herbold, 2013; Swiss Re, 2013b).

Sovereign insurance is deemed appropriate in developing countries suffering from post-disaster financing gaps (see 10.7.4). Current schemes include government disaster reserve funds (FONDEN, Mexico) and pools of small states’ sovereign risks (CCRIF, Caribbean) ((IPCC, 2012)). In both cases, peak risk is transferred to reinsurance and catastrophe bonds (Table 10-7).

10.7.6. Governance, Public-Private Partnerships, and Insurance Market Regulation

10.7.6.1. High-Income Countries

Theory favors an arrangement where individual risk is insured, but the non-diversifiable component of risk (that may rise with climate change) is public ((Borch, 1962); (Kunreuther *et al.*, 2009)). Accordingly, many high-income states have public-private arrangements involving government intervention on peak risk ((Aakre *et al.*, 2010); (Bruggeman *et al.*, 2010); (Schwarze *et al.*, 2011); (Paudel, 2012)) (Table 10-8). The pro-adaptive, risk-reducing features of insurance are more effective if the price reflects the risk and the pool of insured is larger, e.g. through bundled perils ((Bruggeman *et al.*, 2010); (Paudel, 2012)). People who cannot afford premiums can be covered by vouchers, leaving the price signal undistorted, or by subsidies ((Kunreuther *et al.*, 2009); (Aakre *et al.*, 2010)) (Table 10-8). Insurance regulation ensures availability, affordability, and solvency, but often adopts only short- to medium-term views. Because of climate change, regulators have a new role in risk-adequate pricing, risk education, and risk-reduction in the long term ((Hecht, 2008); (Grace and Klein, 2009); (Mills, 2009); (Leurig, 2011)).

[INSERT TABLE 10-8 HERE
Table 10-8: Governance, public-private partnerships, and insurance market regulation.]

10.7.6.2. Middle- and Low-Income Countries

A key element of risk financing is the transfer of private risks to the insurance market. This reduces the governments' burden and uncertainty due to weather disasters ((Ghesquiere and Mahul, 2007)). Interest in public-private partnerships may evolve, e.g. between government, farmers, rural banks and insurers, in order to expedite agricultural development and resilience, e.g. by means of subsidies for start-up costs and the uppermost risk portion ((Collier *et al.*, 2009); (Mahul and Stutley, 2010)) (Table 10-8). As such systems have suffered from adverse selection and moral hazard ((Coble *et al.*, 1997); (Makki and Somwaru, 2001); (Glauber, 2004)), an improved design is needed. For instance, group policies foster mutual monitoring. Well-designed laws and regulations can encourage purchase of insurance. Insurance pools diversify weather risks across larger regions, reduce premiums and improve access to external risk capital ((Mendoza, 2009); (Hochrainer and Mechler, 2011); (Biener and Eling, 2012); (IPCC, 2012)).

In least developed countries, even incipient domestic insurance markets hardly exist. Climate change-related disaster risk management was proposed for inclusion in the adaptation regime of the UNFCCC. Insurance is a central element in these proposals, financed from an UNFCCC adaptation fund according to the principles of "common but differentiated responsibilities and respective capabilities" (UNFCCC Art.3.1) and "polluter pays" ((AOSIS, 2008); (Swiss Confederation, 2008); (MCII, 2008); (Warner and Spiegel, 2009); (Linnerooth-Bayer *et al.*, 2009); (MCII, 2012); (IPCC, 2012)) (Table 10-8).

Innovative insurance concepts, facilitating greater disaster risk capital, are available in middle- and low-income countries, at least at pilot stage. These can advance adaptation to climate change impacts. Everywhere, risk-based premiums foster risk awareness and risk reduction. Challenges include improved risk assessment, with sufficient detail and appropriate dynamics, and scaling-up of successful pilot schemes. Regulatory requirements for risk capital, and access to reinsurance and securitization market further contribute to a resilient insurance system. These are the provisions of sound risk management, even in the absence of climate change.

10.8. Services Other than Tourism and Insurance

Other service sectors of the economy include waste management, wholesale and retail trade, engineering, government, education, defense and health. Contributions to the economy vary substantially by country; however, overall worldwide economic activity related to government accounts for approximately 30% of global expenditures.

10.8.1 Sectors Other than Health

The literature on the impact of climate change on other sectors of the economy is sparse (see Appendix A). Few studies have evaluated the possible impacts of climate change, and particularly the economic impacts, on these sectors. (Tamiotti *et al.*,2009) conducted a qualitative assessment of climate and trade. (Travers and Payne, 1998) and (Subak *et al.*, 2000) find that weather significantly affects retail. (Sabbioni *et al.*, 2009) note that climate change may require a greater effort to protect cultural heritage. Chapter 12 discusses the impact of climate change on violent conflict, which has implications for military expenditures.

10.8.2. Health

Climate change-related alterations in weather patterns, particularly extreme weather and climate events, could affect the health sector through impacts on infrastructure and the delivery of health care services from changing demand. Health care facilities are priority infrastructure that can be damaged by storm surges, floods, wildfires, and other weather and climate events, compromising critical resources required for patient treatment; and physical damage and destruction of equipment and buildings (Carthey et al. 2009). Floods and wildfires can require evacuation of critical care patients, with attendant risks for the patients. Adverse impacts on transportation (such as flooded roads) can exacerbate the situation.

Increased demands for services put additional burdens on public health and health care personnel and supplies, with potential economic consequences. For example, more than 600,000 people required immediate assistance in hydrological events in 2002 through 2010 (EM-DAT 2011). Although the proportion seeking medical treatment are typically a small subset, the additional burden on health care facilities can be significant (Hess et al. 2009). Heatwaves and other extreme events can increase hospitalizations (Chapter 11) with attendant increased costs. Individuals looking for an air-conditioned location during high ambient temperatures also can increase hospital visits (Carthey et al. 2009). One trauma center in the U.S. found a 5.25% increase in hourly admissions for each approximately 5°C increase in temperature; and a 60-78% increase in admission for each 2.5 cm increase in precipitation in the previous three hours (Rising et al. 2006). Very large events that affect multiple health care facilities challenge the ability to properly care for the affected and those with ongoing health issues requiring medication or treatment. Areas projected to experience increases in the frequency and intensity of extreme events could consider additional “surge capacity” to increase the ability of health care facilities to manage such events without interruption of service (Banks et al. 2007; Hess et al. 2009).

Climate change is projected to increase the burden of major worldwide causes of childhood mortality: malnutrition, diarrheal diseases, and malaria (Chapter 11). Any increase in health burdens or risks would increase the demands for public health services (e.g. surveillance and control programs) and the demands for health care and relevant supplies (e.g. oral rehydration). Studies estimating the costs of additional cases of climate-sensitive health outcomes focus on the costs of treatment, not the costs of providing additional health services. Other omitted considerations include the costs of all the health risks of climate change, the costs of implementing new policies, and the costs of hedging health impacts under different scenarios (Hutton, 2011).

Health accounts for approximately 10% of global GDP by expenditure. Estimates of the costs of treating additional cases of climate sensitive health outcomes are in the range of billions of US$ annually (Ebi 2008; Pandey 2010). An estimate of the worldwide costs in 2030 of additional cases of malnutrition, diarrheal disease, and malaria due to climate change, assuming no population or economic growth, emissions reductions resulting in stabilization at 750 ppm CO2 equivalent in 2210, and current costs of treatment in developing countries, estimated treatment costs without adaptation could be $4-12 billion worldwide, depending on assumptions of the sensitivity of these health outcomes to climate change (Ebi 2008). The costs for additional infrastructure and health care workers were not estimated, nor were the costs of additional public health services, such as surveillance and monitoring. The costs were estimated to be unevenly distributed, with most of the costs borne by developing countries, particularly in South East Asia and Africa, to address the projected additional cases of diarrheal disease and malaria (Markandya and Chiabai 2009). The projected additional cases due to climate change were (in millions) 132 for diarrheal diseases; 4.7 for malnutrition; and 22 for malaria. This was against (in millions) 4,514 cases of diarrheal disease, 46 cases of stunting and wasting, and 408 cases of malaria in 2004 (WHO 2004). Development assistance for the health sector in the year 2002 from bilateral and multilateral agencies and foundations was US$ 9.3 billion (Hecht and Shah 2003).

A second global estimate assumed UN population projections, strong economic growth, updated projections of the current health burden of diarrheal diseases and malaria, two climate scenarios, and updated estimates of the costs of malaria treatment (Pandey 2010). In 2010, the average annual adaptation costs for treating diarrheal disease and malaria were estimated to be $3-5 billion, with the costs expected to decline over time with improvement in basic health services. Over the period 2010-2050, the average annual costs were estimated to be around $2 billion, with most of the costs related to treating diarrheal disease; the largest burden is expected to be in Sub-Saharan Africa.

The differences in costs from Ebi (2008) are primarily due to a reduction in the baseline burden of disease and lower costs for malaria treatment.

The malaria estimates from the global estimates of the costs of adaptation are comparable with estimates of the additional health care costs in 2025 in Southern Africa due to a climate change-related increase in the incidence of malaria (Van Rensburg and Blignaut 2002). Assuming low (high) cost scenarios, additional costs for the prevention and treatment of malaria in South Africa were estimated to be approximately $280 (3,764) million, or 0.23% of GDP, in 2025. Estimates for Botswana and Namibia are $ 9 (124) million and $ 13 (177) million, respectively. The high cost scenario for Namibia is about 4.6% of GDP.

(Bosello *et al.*, 2006) used a computable general equilibrium model to study the economic impacts of climate-change-induced changes in the mortality and morbidity due to cardiovascular and respiratory diseases, malaria, diarrhea, schistosomiasis, and dengue fever. They considered the effects on labor productivity and demand for health care, and found that health and welfare impacts have the same sign. The economy-wide health impacts were greater than simple aggregation of the costs of the individual health outcomes. Increased health problems were associated with an expansion of the public sector at the expense of the private sector.

Because any additional climate change-related cases are projected to occur primarily in low-income countries, where no or limited health care is provided by the government, the treatment costs will primarily be borne by families (WHO 2004). Time off from work to care for sick children would affect productivity.

The costs of cases of cholera in Tanzania due to climate change in 2030 were estimated to be in the range of 0.32 – 1.4 % of GDP (Trærup *et al.*, 2011), and the costs of treating additional cases of diarrhea and malaria in 2030 ranged from Rs. 3648–7787 lakhs, depending on the emission scenario (Ramakrishnan, 2011).

10.9. Impacts on Markets and Development

Prior sections of this chapter present the direct impacts of climate change on the economy sector by sector. There are, however, also indirect impacts. The effects that impacts in one sector may have on the rest of the economy are initially presented, followed by the impacts on economic growth and development.

10.9.1. General Equilibrium Effects

General equilibrium analysis describes how climate change impacts in one sector propagate to the rest of the economy, how impacts in one country influence other countries, and how macroeconomic conditions affect each impact (Ginsburgh and Keyzer, 1997). There are three channels through which impact diffuse. First, outputs of one sector are used as inputs to other sectors. For example, a change in crop yields would affect the food-processing industry. Second, products compete for the consumers' finite budget. If, for example, food becomes more expensive, less money would be spent on other goods and services. Third, sectors compete for the primary factors of production (labor, capital, land, water). If more labor is needed in agriculture to offset a drop in crop yields, less labor is available to produce other goods and services. Firms and households react to changes in relative prices, domestically and internationally. Ignoring these effects would lead to biased estimates of the impacts of climate change.

General equilibrium models can provide a comprehensive and internally consistent analysis of the medium-term impact of climate change on economic activity and welfare. However, these models necessarily make a number of simplifying assumptions, particularly with regard to the rationality of consumers and producers and the absence of market imperfections. Partial equilibrium models can be more detailed and more realistic.

Computable general equilibrium models have long been used to study the wider economic implications of changes in crop yields (Kane *et al.*, 1992). (Yates and Strzepek, 1998) show for instance that the impact of a reduced flow of the Nile on the economy of Egypt is much more severe without international trade than with, because trade would allow Egypt to focus on water-extensive production for export and import its food.

Older studies focused on the impact of climate change on patterns of specialization and trade, food prices, food security and welfare (Kane *et al.*, 1992; Reilly *et al.*, 1994; Winters *et al.*, 1998; Yates and Strzepek, 1998; Darwin and Kennedy, 2000; Darwin, 2004). This has been extended to land use (Lee, 2009; Ronneberger *et al.*, 2009), water use (Kane *et al.*, 1992; Calzadilla *et al.*, 2011), and multiple stresses (Reilly *et al.*, 2007). General equilibrium models have also been used to estimate the value of improved weather forecasts (Arndt and Bacou, 2000), a form of adaptation to climate change. Computable general equilibrium analysis has also been used to study selected impacts other than agriculture, notably sea level rise (Darwin and Tol, 2001; Bosello *et al.*, 2007), tourism (Berrittella *et al.*, 2006b; Bigano *et al.*, 2008b), human health (Bosello *et al.*, 2006) and energy (see 10.2).

(Bigano *et al.*, 2008b) study the joint impacts on tourism and coasts, finding that tourism dominates the welfare impacts. (Kemfert, 2002) and (Eboli *et al.*, 2010a) estimate the joint effect on the world economy of a range of climate change impacts, but conflate general equilibrium and growth effects. (Aaheim *et al.*, 2010) analyze the economic effects of impacts of climate change on agriculture, forestry, fishery, energy demand, hydropower production, and tourism on the Iberian peninsula. They find positive impacts on output in some sectors (agriculture, electricity) negative impacts in other sectors (forestry, transport) and negligible ones in others (manufacturing, services). (Ciscar *et al.*, 2011) study the combined impact on agriculture, coasts, river floods and tourism in the current European economy. They find an average welfare loss of 0.2-1.0% of welfare but there are large regional differences with losses in Southern Europe and gains in Northern Europe.

The following initial conclusions emerge. First, markets matter. Impacts are transmitted across locations—with local, regional and global impacts-- and across multiple sectors of the economy. For instance, landlocked countries are affected by sea level rise because their agricultural land increases in value as other countries face erosion and floods. Second, consumers and producers are often affected differently. The price increases induced by a reduction in production may leave producers better off while hurting consumers. Third, the distribution of the direct impacts can be very different than the distribution of the indirect effects. For instance, a loss of production may be advantageous to an individual company or country if the competition loses more. Fourth, a loss of productivity or productive assets in one sector leads to further losses in the rest of the economy. Fifth, markets offer options for adaptation, particularly possibilities for substitution. This changes the size, and sometimes the sign of the impact estimate.

10.9.2. Growth Effects

10.9.2.1. The Rate of Economic Growth

Climate change would also affect economic growth and development, but our understanding is limited. (Fankhauser and Tol, 2005) investigate four standard models of economic growth and three transmission mechanisms: economic production, capital depreciation, and the labor force. They find that, in three models, the fall in economic output is slightly larger than the direct impact on markets while the 4th model (which emphasizes human capital accumulation) points to indirect impacts that are 1.5 times as large as the direct impacts. The difference can be understood as follows. In the three models, the impacts of climate change crowd out consumption and investment in physical capital, while in the fourth model investment in human capital too is crowded out; lower investment implies slower growth. (Hallegatte, 2005) reaches a similar conclusion. (Hallegatte and Thery, 2007; Hallegatte and Ghil, 2008; Hallegatte and Dumas, 2009) highlight that the impact of climate change through natural hazards on economic growth can be amplified by market imperfections and the business cycle. (Eboli *et al.*, 2010a) use a multi-sector, multi-region growth model. The impact of climate change would lead to a 0.3% reduction of GDP in 2050. Regional impacts are more pronounced, ranging from -1.0% in developing countries to +0.4% in Australia and Canada. Sectoral results are varied too, with output changes ranging from output of +0.5% for power generation (to meet increased demand to air conditioning) to -0.7% for natural gas (as demand for space heating falls) and rice.

Using a biophysical model of the human body's ability to do work, (Kjellstrom *et al.*, 2009b) find that by the end of the century climate change may reduce labor productivity by 11-27% in the humid (sub)tropics. Assuming a output elasticity of labor of 0.8, this would reduce economic output in the affected sectors (involving heavy manual labor without air conditioning) by 8-22%. Although structural change in the economy may well reduce the dependence on manual labor and air conditioning would be an effective adaptation, even the ameliorated impact would have a substantial, but as yet unquantified, impact on economic growth.

There are also statistical analyses of the relationship between climate and economic growth. (Barrios *et al.*, 2010) find that the decline in rainfall in the 20th century partly explains the economies of Sub-Saharan Africa have grown more slowly than those of other developing regions. (Brown *et al.*, 2011) corroborate this. (Dell *et al.*, 2012) find that, in the second half of the 20th century, anomalously hot weather slowed down economic growth in poor countries, in both the agricultural and the industrial sectors. (Dell *et al.*, 2009) find that one degree of warming would reduce income by 1.2% in the short run, and by 0.5% in the long run. The difference is due to adaptation. (Horowitz, 2009) finds a much larger effect: a 3.8% drop in income in the long run for one degree of warming.

10.9.2.2. Poverty Traps

Poverty is concentrated in the tropics and subtropics. This has led some analysts to the conclusion that a tropical climate is one of the causes of poverty. (Gallup *et al.*, 1999) emphasize the link between climate, disease, and poverty while (Masters and McMillan, 2001) focus on climate, agricultural pests, and poverty. Other studies (Acemoglu *et al.*, 2001; Acemoglu *et al.*, 2002; Easterly and Levine, 2003) argue that climatic influence on development disappears if differences in human institutions (the rule of law, education, etc) are accounted for. However, (Van der Vliert, 2008) demonstrates that climate affects human culture and thus institutions, but this has yet to be explored in the economic growth literature. (Brown *et al.*, 2011) find that weather affects economic growth in Sub-Saharan Africa – particularly, drought decelerates growth. (Jones and Olken, 2010) find that exports from poor countries fall during hot years. (Bloom *et al.*, 2003) find limited support for an impact of climate (rather than weather) on past growth in a single-equilibrium model, but strong support in a multiple-equilibrium model: Hot and wet conditions and large variability in rainfall reduce long-term growth in poor countries (but not in hot ones) and increase the probability of being poor.

(Galor and Weil, 1996) speculate about the existence of a climate-health-poverty trap. (Strulik, 2008; Bonds *et al.*, 2010; Bretschger and Valente, 2011; Ikefuji and Horii, 2012) posit theoretical models and offer limited empirical support, while (Tang *et al.*, 2009) offers more rigorous empirical evidence. This is further supported by yet-to-be-published analyses (Gollin and Zimmermann, 2008; Bretscher and Valente, 2010; Gollin and Zimmermann, 2010; Ikefuji *et al.*, 2010). Climate-related diseases such as malaria and diarrhea impair children’s cognitive and physical development. This leads to poverty in their later life so that there are limited means to protect their own children against these diseases. Furthermore, high infant mortality may induce parents to have many children so that the investment in education is spread thin. An increase in infant and child mortality and morbidity due to climate change would thus trap more people in poverty.

(Zimmerman and Carter, 2003; Ikefuji and Horii, 2012) build a model in which the risk of natural disasters causes a poverty trap: At higher risk levels, households prefer assets with a safe but low return. (Carter *et al.*, 2007) find empirical support for this model at the household level, but (van den Berg, 2010) concludes the natural disaster itself has no discernible impact on investment choices. At the macro-economic level, natural disasters disproportionally affect the growth rate of poor countries (Noy, 2009).

(Devitt and Tol, 2012) construct a model with conflict-poverty trap, and show that climate change may exacerbate this. (Bougheas *et al.*, 1999; Bougheas *et al.*, 2000) show that more expensive infrastructure, for example because of frequent repairs after natural disasters, slows down economic growth and that there is a threshold infrastructure cost above which trade and specialization do not occur, suggesting another mechanism through which climate could cause a poverty trap. The implications of climate change have yet to be assessed.

10.9.2.3. Conclusion

In sum, the literature on the impact of climate and climate change on economic growth and development has yet to reach firm conclusions. There is agreement that climate change would slow economic growth, by a little according to some studies and by a lot according to other studies. There is disagreement whether climate change would affect the nature of economic development, with some studies suggesting that more people may be trapped in poverty and fewer people enjoying exponential growth.

10.10. Research Needs and Priorities

Evaluating the economic aspects of the impacts has emerged as an active research area. Initial work has developed in a few key economic sectors and through economy wide economic assessments. Data, tools and methods continue to evolve to address additional sectors and more complex interactions among the sectors in the economic systems and a changing climate.

Based on a comprehensive assessment across economic sectors, few key sectors have been subject to detailed research. Multiple aspects of energy impacts have been assessed, but others remain to be evaluated, particularly economic impact assessments of adaptation both on existing and future infrastructure, but also the costs and benefits for future systems under differing climatic conditions. Studies focused on the impacts of climate change on the energy sector indicate both potential benefits and detrimental impacts across developed and developing countries. In energy supply, the deployment of extraction, transport and processing infrastructure, power plants and other installations are expected to proceed rapidly in developing countries in the coming decades to satisfy fast growing demand for energy. Designing newly deployed facilities with a view to projected changes in climate attributes and extreme weather patterns would require targeted inquiries into the impacts of climate change on the energy related resource base, conversion and transport technologies.

The economics of climate change impacts on transportation systems and their role in overall economic activity have yet to be well understood. For water related sectors, improved estimation of flood damages to economic sectors, research on economic impacts of ecosystems, rivers, lakes and wetlands, ecosystems service, and tourism and recreation are needed. Economic assessments of adaptation strategies such as water savings technologies, particularly for semi-arid and arid developing countries, are also needed. Further, detailed studies are needed of the integrated impact of climate change on all water-dependent economic sectors, as existing studies do not examine competitiveness between water uses among sectors and economic productivity.

Although both tourism and recreation are sensitive to climate change, the literature on tourism is far more extensive. Current studies either have a rudimentary representation of the effect of weather and climate but a detailed representation of substitution between holiday destination and activities, or a detailed representation of the immediate impact of climate change but a rudimentary representation of alternatives to the affected destinations or activities.

Considerable research has been developed related to climate change and associated weather risk to insurance; however, limited research has been published on observed trends in normalized insured climate-related losses as compared to trends in direct economic climate-related losses, including insured property and agriculture losses as compared to direct economic losses. Additionally, no quantitative study could be found for projected impacts on health and life insurance, and only few on regional markets including scenarios on hazard, exposure, vulnerability and adaption status, regulation, risk capital availability. Furthermore, little is known regarding the temporal changes of vulnerability for insured risk such as how susceptibilities of structures to damage changed in the past and can be projected to change in the future.

Little literature exists on potential climate impacts on other economic sectors, such as mining, manufacturing, and services (apart from health, insurance and tourism); in particular assessments of whether these sectors are indeed sensitive to climate and climate change.

The spillover effects of the impacts of climate change in one sector on other markets are understood in principle, but the number of quantitative studies is too few to place much confidence in the numerical results. Similarly, the impact of climate and climate change on economic growth and development is not well understood, with some studies pointing to a small or negligible effect and other studies arguing for a large or dominant effect.

Frequently Asked Questions

FAQ 10.1: Why are key economic sectors vulnerable to climate change?
Many key economic sectors are impacted by changing climate conditions, related long term changes in temperature, precipitation, sea level rise, and extreme events. For example, in addition to many other purposes, energy is used to keep buildings warm in winter and cool in summer. A change in temperature would thus affect energy demand. Climate change affects energy supply, among others, through the cooling of thermal plant, though wind, solar and water resources, and through transport and transmission infrastructure. Water demand increases with temperature but falls with rising carbon dioxide concentrations. Water supply depends on precipitation patterns and temperature, and water infrastructure is vulnerable to extreme weather, while transport infrastructure is designed to withstand a particular range of weather conditions and climate change would expose this infrastructure to weather outside historical design criteria. Tourism is also affected by climate change, as most people prefer to spend part of their free time outdoors, be it hiking, skiing, or lazing on a beach in the sun. Climate change would lead people to enjoy themselves differently, at different times, and in different places. Health care systems are also impacted, as climate change affects a number of diseases and thus the demand for and supply of health care.

FAQ 10.2: How does climate change impact the financial services industry?
Insurance buys financial security against, among other perils, weather hazards. Climate change impacts, including increased weather variability, are anticipated to increase losses and loss variability in various regions through more frequent and/or intensive weather disasters. This will challenge insurance systems to offer coverage for premiums that are still affordable, while at the same time require more risk-based capital. Adequate insurance coverage will be challenging in low- and middle-income countries.

FAQ 10.3: Are other economic sectors vulnerable to climate change too?
Economic activities such as agriculture, forestry, fisheries and mining are exposed to the weather and thus vulnerable to climate change. Other economic activities, such as manufacturing and services, largely take place in controlled environments and are not really exposed to climate change. However, markets connect sectors so that the impacts of climate change spillover from one activity to all others. The impact of climate change on economic development and growth also affects all sectors.

Cross-Chapter Box

Box CC-WE. The Water-Energy-Food Nexus as Linked to Climate Change

[Douglas J. Arent (USA), Petra Döll (Germany), Ken Strzepek (UNU/USA), FerencToth (IAEA/Hungary), Blanca Elena Jimenez Cisneros (Mexico), Taikan Oki (Japan)]

Water, energy, and food are linked through numerous interactive pathways and subject to a changing climate, as depicted in Figure CC-WE-1. The depth and intensity of those linkages vary enormously between regions and production systems. Some energy technologies (biofuels, hydropower, thermal power plants), transportation fuels and modes and food products (from irrigated crops, in particular animal protein produced by feeding irrigated crops) require more water than others (Chapter 3.7.2, 7.3.2, 10.2,10.3.4, McMahon and Price, 2011, Macknick et al, 2012a, Cary and Weber 2008). In irrigated agriculture, climate, crop choice and yields determine water requirements per unit of produced crop, and in areas where water must be pumped or treated, energy must be provided (Kahn and Hajra 2009, Gertenet al. 2011). While food production and transport require large amounts of energy (Pelletier et al 2011), a major link between food and energy as related to climate change is the competition of bioenergy and food production for land and water (7.3.2, Diffenbaugh et al 2012, Skaggs et al, 2012).

[INSERT FIGURE WE-1 HERE
Figure WE-1: The water-energy-food nexus as related to climate change.]

Most energy production methods require significant amounts of water, either directly (e.g. crop-based energy sources and hydropower) or indirectly (e.g., cooling for thermal energy sources or other operations) (Chapter 10.2.2 and 10.3.4, and Davies et al 2013, van Vliet et al 2012). Water is also required for mining, processing, and residue disposal of fossil fuels. Water for biofuels, for example, has been reported by Gerbens-Leenes et al. 2012 who computed a scenario of water use for biofuels for transport in 2030 based on the Alternative Policy Scenario of the IEA. Under this scenario, global consumptive irrigation water use for biofuel production is projected to increase from 0.5% of global renewable water resources in 2005 to 5.5% in 2030, resulting in increased pressure on freshwater resources, with potential negative impacts on freshwater ecosystems. Water for energy currently ranges from a few percent to more than 50% of freshwater withdrawals, depending on the region and future water requirements will depend on electric demand growth, the portfolio of generation technologies and water management options employed (WEC 2010, Sattler et al., 2012). Future water availability for energy production will change due to climate change (Chapter 3.5.2.2).

Water may require significant amounts of energy for lifting, transport and distribution, treatment or desalination. Non-conventional water sources (wastewater or seawater) are often highly energy intensive. Energy intensities per m^3 of water vary by about a factor of 10 between different sources, e.g. locally produced or reclaimed wastewater vs. desalinated seawater (Plappally and Lienhard 2012, Macknick et al, 2012b). Groundwater (35% of total global water withdrawals, with irrigated food production being the largest user, Döll et al. 2012) is generally more energy intensive than surface water – in some countries, 40% of total energy use is for pumping groundwater. Pumping from greater depth (following falling groundwater tables) increases energy demand significantly– electricity use ($kWhr/m^3$) increases by a factor of 3 when going from 35 to 120 m depth (Plappally and Lienhard 2012). A lack of water security can lead to increasing energy demand and vice versa, e.g. over-irrigation in response to electricity or water supply gaps.

Other linkages through land use and management, e.g. afforestation, can affect water as well as other ecosystem services, climate and water cycles (4.4.4, Box 25-10). Land degradation often reduces efficiency of water and energy use (e.g. resulting in higher fertilizer demand and surface runoff), and many of these interactions can compromise food security (3.7.2, 4.4.4). Only a few reports have begun to evaluate the multiple interactions among energy, food, land, and water (McCornick *et al.*, 2008, Bazilian *et al.*, 2011, Bierbaum and Matson, 2013), addressing the issues from a security standpoint and describing early integrated modeling approaches. The interaction among each of these factors is influenced by the changing climate, which in turn impacts energy demand, bioproductivity and other factors (see Figure WE-1 and Wise et al, 2009), and has implications for security of supplies of energy, food and water, adaptation and mitigation pathways, air pollution reduction as well as the implications for health and economic impacts as described throughout this Assessment Report.

CC-WE References

Bazilian, M. Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, R.S.J., Yumkella, K., ; Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy, Volume 39, Issue 12, December 2011, Pages 7896-7906*

Bierbaum, R., and P. Matson, “Energy in the Context of Sustainability”, Daedalus, The Alternative Energy Future, Vol.2, 90-97, 2013.

Döll, P., Hoffmann-Dobrev, H., Portmann, F.T., Siebert, S., Eicker, A., Rodell, M., Strassberg, G., Scanlon, B. (2012): Impact of water withdrawals from groundwater and surface water on continental water storage variations. J. Geodyn. 59-60, 143-156, doi:10.1016/j.jog.2011.05.001.

Davies, E., Page, K. and Edmonds, J. A., 2013. "An Integrated Assessment of Global and Regional Water Demands for Electricity Generation to 2095." *Advances in Water Resources* 52:296–313.10.1016/j.advwatres.2012.11.020.

Diffenbaugh, N.,Hertel, T., M. Scherer & M. Verma, “Response of corn markets to climate volatility under alternative energy futures”, Nature Climate Change 2, 514–518 (2012)

Gerten D., Heinke H., Hoff H., Biemans H., Fader M., Waha K. (2011): Global water availability and requirements for future food production, Journal of Hydrometeorology, doi: 10.1175/2011JHM1328.1.

Khan, S., Hanjra, M. A. 2009. Footprints of water and energy inputs in food production - Global perspectives. Food Policy, 34, 130-140.
King, C**.** and Webber, M**.** E., Water intensity of transportation, Environmental Science and Technology, 2008, 42 (21), 7866-7872.
Macknick, J., Newmark, R., Heath, G., Hallett, K.C., Meldrum, J., Nettles-Anderson, S. (2012). Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies: A Review of Existing Literature", Environmental Research Letters. Vol. 7(4), 2012a
Macknick, J., Sattler, S., Averyt, K., Clemmer, S., Rogers, J. (2012). Water Implications of Generating Electricity: Water Use Across the United States Based on Different Electricity Pathways through 2050." Environmental Research Letters. Vol. 7(4), 2012b
McCornick P.G., Awulachew S.B. and Abebe M. (2008): Water-food-energy-environment synergies and tradeoffs: major issues and case studies. Water Policy, 10: 23-36.
Plappally, A.K., and J.H. Lienhard V; Energy requirements for water production, treatment, end use, reclamation, and disposal;*Renewable and Sustainable Energy Reviews*, *Volume 16, Issue 7, September 2012*, *Pages 4818-4848*
Pelletier, N., Audsley, E. , Brodt, S. , Garnett, T., Henriksson, P,. Kendall, A., Kramer, K.J. , Murphy, D., Nemeck, T. and M. Troell, "Energy Intensity of Agriculture and Food Systems", Annual Review of Environment and Resources,36: 223-246, 2011.
Sattler, S., Macknick, J., Yates, D., Flores-Lopez, F., Lopez, A., Rogers, J. (2012). Linking Electricity and Water Models to Assess Electricity Choices at Water-Relevant Scales. Environmental Research Letters. Vol. 7(4), October-December 2012
Shah T. (2007): Groundwater, a global assessment of scale and significance, in: Molden (ed) Comprehensive Assessment of Water Management in Agriculture, Earthscan, Colombo, International Water Management Institute.
Skaggs, R., Janetos, TC, Hibbard, KA , Rice, JS, Climate and Energy-Water-Land System Interactions; Technical Report to the U.S. Department of Energy in Support of the National Climate Assessment, PNNL report 21185, March 2012
van Vliet, M.T.H., , J.R., Ludwig, F., Vögele, S., Lettenmaier, D. P., and Kabat, P. , Vulnerability of US and European electricity supply to climate change. Nature Climate Change, 2, 676–681(2012).
Wise, M., Calvin, K., Thomson, A., Clarke, L., Bond-Lamberty, B., Sands, R., Smith, S.J., Janetos, A, Edmonds, J. 2009. Implications of limiting CO2 concentrations for land use and energy. Science 324, 1183-1186.
World Energy Council; Water for Energy; 2010.

Appendix 10.A1. Industrial Classification and Chapter Outline

International Standard Industrial Classification (ISIC) of All Economic Activities, Rev.4, the outline of Chapter 10, and nil returns in a literature search on Scopus.

- A - Agriculture, forestry and fishing (10.5)
  - 01 - Crop and animal production, hunting and related service activities
  - 02 - Forestry and logging
  - 03 - Fishing and aquaculture
- B - Mining and quarrying (10.5)
  - 05 - Mining of coal and lignite
  - 06 - Extraction of crude petroleum and natural gas
  - 07 - Mining of metal ores
  - 08 - Other mining and quarrying
    - Climate change impact & quarrying: No results*
  - 09 - Mining support service activities
- C – Manufacturing (10.5, except C19)
  - 10 - Manufacture of food products
    - Climate change impact & food products: No results*
    - Climate change impact & food processing: No results*
  - 11 - Manufacture of beverages
    - Climate change impact & beverages: No results*
  - 12 - Manufacture of tobacco products
    - Climate change impact & tobacco: No results*
  - 13 - Manufacture of textiles
    - Climate change impact & textiles: No results*
  - 14 - Manufacture of wearing apparel
    - Climate change impact & apparel: No results*
  - 15 - Manufacture of leather and related products

        - Climate change impact & leather: No results*
    - 16 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
        - Climate change impact & wood: No results*
    - 17 - Manufacture of paper and paper products
        - Climate change impact & pulp paper: No results*
    - 18 - Printing and reproduction of recorded media
        - Climate change impact & printing: No results*
        - Climate change impact & recorded media: No results*
    - 19 - Manufacture of coke and refined petroleum products (10.2)
    - 20 - Manufacture of chemicals and chemical products
        - Climate change impact & chemical production: No results*
    - 21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations
        - Climate change impact & pharmaceutical: No results*
    - 22 - Manufacture of rubber and plastics products
        - Climate change impact & rubber: No results*
        - Climate change impact & plastic: No results*
    - 23 - Manufacture of other non-metallic mineral products
        - Climate change impact & cement: No results*
        - Climate change impact & glass: No results*
    - 24 - Manufacture of basic metals
        - Climate change impact & steel: No results*
        - Climate change impact & iron: No results*
        - Climate change impact & alumina: No results*
        - Climate change impact & aluminum: No results*
    - 25 - Manufacture of fabricated metal products, except machinery and equipment
        - Climate change impact & metal: No results*
    - 26 - Manufacture of computer, electronic and optical products
        - Climate change impact & equipment: No results*
    - 27 - Manufacture of electrical equipment
        - Climate change impact & equipment: No results*
    - 28 - Manufacture of machinery and equipment n.e.c.
        - Climate change impact & equipment: No results*
        - Climate change impact & machinery: No results*
    - 29 - Manufacture of motor vehicles, trailers and semi-trailers
        - Climate change impact & vehicle: No results*
    - 30 - Manufacture of other transport equipment
        - Climate change impact & equipment: No results*
    - 31 - Manufacture of furniture
        - Climate change impact & furniture: No results*
    - 32 - Other manufacturing
    - 33 - Repair and installation of machinery and equipment
        - Climate change impact & equipment: No results*
        - Climate change impact & machinery: No results*
- D - Electricity, gas, steam and air conditioning supply (10.2)
    - 35 - Electricity, gas, steam and air conditioning supply
- E - Water supply; sewerage, waste management and remediation activities
    - 36 - Water collection, treatment and supply (10.3)
    - 37 – Sewerage (10.3)
    - 38 - Waste collection, treatment and disposal activities; materials recovery (10.8)
    - 39 - Remediation activities and other waste management services (10.8)
- F – Construction (10.5)
    - 41 - Construction of buildings
    - 42 - Civil engineering

  - 43 - Specialized construction activities
- G - Wholesale and retail trade; repair of motor vehicles and motorcycles (10.8)
  - 45 - Wholesale and retail trade and repair of motor vehicles and motorcycles
  - 46 - Wholesale trade, except of motor vehicles and motorcycles
  - 47 - Retail trade, except of motor vehicles and motorcycles
- H - Transportation and storage (10.4)
  - 49 - Land transport and transport via pipelines
  - 50 - Water transport
  - 51 - Air transport
  - 52 - Warehousing and support activities for transportation
  - 53 - Postal and courier activities
- I - Accommodation and food service activities (10.6)
  - 55 - Accommodation
  - 56 - Food and beverage service activities
- J - Information and communication (10.8)
  - 58 - Publishing activities
  - 59 - Motion picture, video and television programme production, sound recording and music publishing activities
  - 60 - Programming and broadcasting activities
  - 61 - Telecommunications
  - 62 - Computer programming, consultancy and related activities
  - 63 - Information service activities
- K - Financial and insurance activities (10.7)
  - 64 - Financial service activities, except insurance and pension funding
  - 65 - Insurance, reinsurance and pension funding, except compulsory social security
  - 66 - Activities auxiliary to financial service and insurance activities
- L - Real estate activities (10.8)
  - 68 - Real estate activities
- M - Professional, scientific and technical activities (10.8)
  - 69 - Legal and accounting activities
  - 70 - Activities of head offices; management consultancy activities
  - 71 - Architectural and engineering activities; technical testing and analysis
  - 72 - Scientific research and development
  - 73 - Advertising and market research
  - 74 - Other professional, scientific and technical activities
  - 75 - Veterinary activities
- N - Administrative and support service activities (10.8 except N79)
  - 77 - Rental and leasing activities
  - 78 - Employment activities
  - 79 - Travel agency, tour operator, reservation service and related activities (10.6)
  - 80 - Security and investigation activities
  - 81 - Services to buildings and landscape activities
  - 82 - Office administrative, office support and other business support activities
- O - Public administration and defence; compulsory social security (10.8)
  - 84 - Public administration and defence; compulsory social security
- P – Education (10.8)
  - 85 - Education
- Q - Human health and social work activities (10.8)
  - 86 - Human health activities
  - 87 - Residential care activities
  - 88 - Social work activities without accommodation
- R - Arts, entertainment and recreation (10.6)
  - 90 - Creative, arts and entertainment activities
  - 91 - Libraries, archives, museums and other cultural activities

- 92 - Gambling and betting activities
- 93 - Sports activities and amusement and recreation activities
- S - Other service activities (10.8)
    - 94 - Activities of membership organizations
    - 95 - Repair of computers and personal and household goods
    - 96 - Other personal service activities
- T - Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use (10.8)
    - 97 - Activities of households as employers of domestic personnel
    - 98 - Undifferentiated goods- and services-producing activities of private households for own use
- U - Activities of extraterritorial organizations and bodies (10.8)
    - 99 - Activities of extraterritorial organizations and bodies

*No results = no results for the impact of climate change on this particular economic activity. There may be results for the impact of climate change on a related activity, or for the impact of the activity on climate change.

References

*Adaptation of Forests and People to Climate Change -- A Global Assessment Report.*2009: . In: IUFRO World Series [Seppala, R., Buck, A. and Katila, P. (eds.)]. International Union of Forest Research Organizations, Helsinki.

2013: *AgroClima. Informática Avanzada SA de CV.* http://www.agroclima.com.mx/

Aaheim, A., H. Amundsen, T. Dokken, T. Ericson, and T. Wei, 2009: A macroeconomic assessment of impacts and adaptation of climate change in Europe. *CICERO Report*, **6**.

Aaheim, A., T. Dokken, S. Hochrainer, A. Hof, E. Jochem, R. Mechler, and D.P. van Vuuren, 2010: National responsibilities for adaptation strategies: lessons from four modelling framework. In: *Making Climate Change Work for Us: European Perspectives on Adaptation and Mitigation Strategies.* [Hulme, M. and H. Neufeldt(eds.)]. Cambridge University Press, Cambridge, pp. 87-112.

Aakre, S., I. Banaszak, R. Mechler, D. Rübbelke, A. Wreford, and H. Kalirai, 2010: Financial adaptation to disaster risk in the European Union. *Mitigation and Adaptation Strategies for Global Change,* **15**, 721-736.

Abegg, B. and H. Elsasser, 1996: Climate, weather, and tourism in the Swiss alps. *Geographische Rundschau,* **48(12)**, 737-742.

ABI, 2005: Financial risk of climate change. *Association of British Insurers,* , 39.

Acemoglu, D., S. Johnson, and J.A. Robinson, 2001: The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review,* **91(4)**, 1369-1401.

Acemoglu, D., S. Johnson, and J.A. Robinson, 2002: Reversal of fortune: Geography and institutions in the making of the modern world income distribution. *Quarterly Journal of Economics,* **117(4)**, 1231-1294.

Acosta Moreno, R., 1995: IPCC SAR
. **WG II**.

ADAM-Project, 2009: *Policy Appraisal for the Electricity Sector: Impacts, Mitigation, Adaptation, and Long Term Investments for Technological Change,* [Programme, European Community's Framework 6 (ed.)]. EU FP-6 programme, Brussels, Belgium.

Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit, and K. Takahashi, 2007: Assessment of adaptation practices, options, constraints and capacity. *Clim.Change,* , 717-743.

Aerts, J.C.J.H. and W.J.W. Botzen, 2011: Climate change impacts on pricing long-term flood insurance: a comprehensive study for the Netherlands. *Global Environmental Change,* **21**, 1045-1060.

Ahn, S., J.E. De Steiguer, R.B. Palmquist, and T.P. Holmes, 2000: Economic analysis of the potential impact of climate change on recreational trout fishing in the Southern Appalachian Mountains: An application of a nested multinomial logit model. *Climatic Change,* **45(3-4)**, 493-509.

Allison, E.H., A.L. Perry, M.-. Badjeck, W. Neil Adger, K. Brown, D. Conway, A.S. Halls, G.M. Pilling, J.D. Reynolds, N.L. Andrew, and N.K. Dulvy, 2009: Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries,* **10(2)**, 173-196.

Álvarez-Díaz, M. and J. Rosselló-Nadal, 2010: Forecasting British tourist arrivals in the Balearic Islands using meteorological variables. *Tourism Economics*, **16(1)**, 153-168.
Amelung, B. and D. Viner, 2006: Mediterranean tourism: Exploring the future with the tourism climatic index. *Journal of Sustainable Tourism*, **14(4)**, 349-366.
Amelung, B., S. Nicholls, and D. Viner, 2007: Implications of global climate change for tourism flows and seasonality. *Journal of Travel Research*, **45(3)**, 285-296.
Amelung, B. and A. Moreno, 2012: Costing the impact of climate change on tourism in Europe: Results of the PESETA project. *Climatic Change*, **112(1)**, 83-100.
Amengual, A., V. Homar, R. Romero, S. Alonso, and C. Ramis, 2012: Projections of the climate potential for tourism at local scales: Application to Platja de Palma, Spain. *International Journal of Climatology*, **32(14)**, 2095-2107.
Antonioni, G., S. Bonvicini, G. Spadoni, and V. Cozzani, 2009: Development of a General Framework for the risk assessment of Na-Tech Accidents. *Reliability Engineering and System Safety*, **94**, 1442-1450.
AOSIS, 2008: Multi-window mechanism to address loss and damage from climate change impacts.Proceedings of Submission of the Alliance of Small Island States (AOSIS) to the UNFCCC: Proposal to the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA). December 1-10, 2008, Poznan, pp. 1-8.
Apipattanavis, S., K. Sabol, K.R. Molenaar, B. Rajagopalan, Y. Xi, B. Blackard, and S. Patil, 2010: Integrated framework for quantifying and predicting weather-related highway construction delays. *Journal of Construction Engineering and Management*, **136(11)**, 1160-1168.
Arkell, B.P. and G.J.C. Darch, 2006: Impact of Climate Change on London's Transport Network. *Municipal Engineer*, **159(ME4)**, 231.
Arndt, C., Thurlow J., 2012: Impacts on Climate Change on Development Paths for Mozambique. *Review of International Economics*, .
Arndt, C. and M. Bacou, 2000: Economy-wide effects of climate variability and climate prediction in Mozambique. *American Journal of Agricultural Economics*, **82(3)**, 750-754.
Arrow, K.J. and R.C. Lind, 1970: Uncertainty and the evaluation of public investment decisions. *The American Economic Review*, **60(3)**, 364-378.
Barlas, T.K. and G.A.M. Van Kuik, 2010: Review of State of the Art in Smart Rotor Control Research for Wind Turbines. *Progress in Aerospace Sciences*, **46**, 1-27.
Barnett, B.J., C.B. Barrett, and J.R. Skees, 2008: Poverty traps and index-based risk transfer products. *World Development*, **36(10)**, 1766-1785.
Barredo, J.I., D. Sauri, and M.C. Llasat, 2012: Assessing trends in insured losses from floods in Spain 1971-2008. *Natural Hazards and Earth System Sciences*, **12(5)**, 1723-1729 (Doi:10.5194/nhess-12-1723-2012).
Barrieu, P. and H. Loubergé, 2009: Hybrid cat bonds. *The Journal of Risk and Insurance*, **76(3)**, 547-578.
Barrios, S., L. Bertinelli, and E. Strobl, 2010: Trends in rainfall and economic growth in Africa: A neglected cause of the african growth tragedy. *Review of Economics and Statistics*, **92(2)**, 350-366.
Barthel, F. and E. Neumayer, 2012: A trend analysis of normalized insured damage from natural disasters. *Climatic Change*, **113**, 215-237 (DOI 10.1007/s10584-011-0331-2).
Barthelmie, R.J., F. Murray, and S.C. and Pryor, 2008: The economic benefit of short-term forecasting for wind energy in the UK electricity market. *Energy Policy*, **36**, 1687-1696.
Bashmakov, A.I., Bruckner, T., Mulugetta, Y. forthcoming: Energy Systems. Chapter 7 in the IPCC AR5 WGIII.
Bayliss, C., 2007: Transmission and distribution in electrical engineering. *Fuel and Energy Abstracts*, **37(3)**, 195-195.
Becken, S., 2005: Harmonising climate change adaptation and mitigation: The case of tourist resorts in Fiji. *Global Environmental Change*, **15(4)**, 381-393.
Becken, S. and J. Hay, 2007: *Tourism and climate change: Risks and opportunities.* Channel View Publications, Clevedon, .
Becker, A., S. Inoue, M. Fischer, and B. Schwegler, 2011: Climate Change Impacts on International Seaports: Knowledge, Perceptions, and Planning Efforts Among Port Adminstrators. *Climatic Change*, .
Belle, N. and B. Bramwell, 2005: Climate change and small island tourism: Policy maker and industry perspectives in Barbados. *Journal of Travel Research*, **44(1)**, 32-41.
Bengtsson, L., K. Hodges, and E. Roeckner, 2006: Storm Tracks and Climate Change. *Journal of Climate*, **19**, 3518-3543.

Berrittella, M., A. Bigano, R. Roson, and R.S.J. Tol, 2006a: A general equilibrium analysis of climate change impacts on tourism. *Tourism Management,* **27(5)**, 913-924.

Berrittella, M., A. Bigano, R. Roson, and R.S.J. Tol, 2006b: A general equilibrium analysis of climate change impacts on tourism. *Tourism Management,* **27(5)**, 913-924.

Bicknell, S. and P. Mcmanus, 2006: The canary in the coalmine: Australian ski resorts and their response to climate change. *Geographical Research,* **44(4)**, 386-400.

Biener, C. and M. Eling, 2012: Insurability in Microinsurance Markets: An Analysis of Problems and Potential Solutions. *The Geneva Papers,* **37(1)**, 77-107 (Doi: 10.1057/gpp.2011.29).

Bigano, A., J.M. Hamilton, and R.S.J. Tol, 2006: The impact of climate on holiday destination choice. *Climatic Change,* **76(3-4)**, 389-406.

Bigano, A., J.M. Hamilton, and R.S.J. Tol, 2007: *The Impact of Climate Change on Domestic and International Tourism: A Simulation Study*. *Integrated Assessment Journal,* **7(1)**, 25-49.

Bigano, A., F. Bosello, R. Roson, and R.S.J. Tol, 2008a: Economy-wide impacts of climate change: A joint analysis for sea level rise and tourism. *Mitigation and Adaptation Strategies for Global Change,* **13(8)**, 765-791.

Bigano, A., F. Bosello, R. Roson, and R.S.J. Tol, 2008b: Economy-wide impacts of climate change: A joint analysis for sea level rise and tourism. *Mitigation and Adaptation Strategies for Global Change,* **13(8)**, 765-791.

Block, P. and K.M. Strzepek, 2012: Impacts and Adaptation of the Hydropower Systems in Ethiopia. *Review of International Economics,* .

Bloom, A., V. Kotroni, and K. Lagouvardos, 2008: Climate change impact of wind energy availability in the Eastern Mediterranean using the regional climate model PRECIS. *Natural Hazards and Earth System Sciences,* **8**, 1249-1257.

Bloom, D.E., D. Canning, and J. Sevilla, 2003: Geography and poverty traps. *Journal of Economic Growth,* **8(4)**, 355-378.

Bonds, M.H., D.C. Keenan, P. Rohani, and J.D. Sachs, 2010: Poverty trap formed by the ecology of infectious diseases. *Proceedings of the Royal Society B: Biological Sciences,* **277(1685)**, 1185-1192.

Borch, K., 1962: Equilibrium in a reinsurance market. *Econometrica,* **30(3)**, 424-444.

Bosello, F., E. De Cian, and R. Roson, 2007: Climate Change, Energy Demand and Market Power in a General Equilibrium Model of the World Economy. *CMCC Research Paper,* **No. 10**.

Bosello, F., C. Carraro, and E. De Cian, 2009: An Analysis of Adaptation as a Response to Climate Change. *University Ca' Foscari of Venice,* **Dept. of Economics Research Paper Series No. 26_09**.

Bosello, F., R. Roson, and R.S.J. Tol, 2006: Economy-wide estimates of the implications of climate change: Human health. *Ecological Economics,* **58(3)**, 579-591.

Bosello, F., R. Roson, and R.S.J. Tol, 2007: Economy-wide estimates of the implications of climate change: Sea level rise. *Environmental and Resource Economics,* **37(3)**, 549-571.

Bosse, S. and P.M. Liedtke, 2009: The relevance of insurance to climate-sensitive economic development. In: *The Geneva Reports - Risk and Insurance Research, No. 2.The insurance industry and climate change - Contribution to the global debate.* [Liedtke, P.M. (ed.)]. The Geneva Association, Geneva, pp. 9-21.

Botzen, W.J.W. and J.C.J.M. van den Bergh, 2008: Insurance against climate change and flooding in the Netherlands: present, future, and comparison with other countries. *Risk Analysis,* **28(2)**, 413-426.

Botzen, W.J.W., J.C.J.H. Aerts, and J.C.J.M. van den Bergh, 2009: Willingness of homeowners to mitigate climate risk through insurance. *Ecological Economics,* **68**, 2265-2277.

Botzen, W.J.W. and J.C.J.M. van den Bergh, 2009: Bounded rationality, climate risks, and insurance: Is there a market for natural disasters? *Land Economics,* **85(2)**, 265-278.

Botzen, W.J.W., J.C.J.M. van den Bergh, and L.M. Bouwer, 2010a: Climate change and increased risk for the insurance sector: a global perspective and an assessment for the Netherlands. *Natural Hazards,* **52**, 577-598.

Botzen, W.J.W., L.M. Bouwer, and J.C.J.M. van den Bergh, 2010b: Climate change and hailstorm damage: Empirical evidence and implications for agriculture and insurance. *Resource and Energy Economics,* **32**, 341-362.

Bougheas, S., P.O. Demetriades, and E.L.W. Morgenroth, 1999: Infrastructure, transport costs and trade. *Journal of International Economics,* **47(1)**, 169-189.

Bougheas, S., P.O. Demetriades, and T.P. Mamuneas, 2000: Infrastructure, specialization, and economic growth. *Canadian Journal of Economics,* **33(2)**, 506-522.

Bourdeau, P., 2009: From après-ski to après-tourism: The alps in transition? Reflections based on the French situation. *Revue De Geographie Alpine,* **97(3)**.

Bouwer, L.M., 2011: Have disaster losses increased due to anthropogenic climate change? *Bulletin of the American Meteorological Society*, **92**, 39-46.
Bouwer, L.M., R.P. Crompton, E. Faust, P. Höppe, and R.A. Pielke Jr., 2007: Confronting disaster losses. *Science,* **318(5851)**, 753.
Boyd, R. and M.E. Ibarraran, 2009: Extreme Climate Events and Adaptation: An Exploratory Analysis of Drought in Mexico. *Environment and Development Economics,* **14**, 371-395.
Brander, L.M., K. Rehdanz, R.S.J. Tol, and P.H.J. van Beukering, 2012: The economic impact of ocean acidification on coral reefs. *Climate Change Economics,* **3(1)**, 1-29.
Bretscher, L. and S. Valente, 2010: *Uneven Development due to Climate Change -- Growth Effects of Climate Change Exposure and Adaptation.* Centre of Economic Research, ETH, Zurich.
Bretschger, L. and S. Valente, 2011: Climate change and uneven development. *Scandinavian Journal of Economics,* **113(4)**, 825-845.
Brown, C., R. Meeks, K. Hunu, and W. Yu, 2011: Hydroclimate risk to economic growth in sub-Saharan Africa. *Climatic Change,* **106(4)**, 621-647.
Bruggeman, V., M.G. Faure, and K. Fiore, 2010: The government as reinsurer of catastrophe risks. *The Geneva Papers*, **35**, 369-390.
Buckley, L.B. and M.S. Foushee, 2012: Footprints of climate change in US national park visitation. *International Journal of Biometeorology*, **56(6)**, 1173-1177.
Bujosa, A. and J. Rosselló, 2012: Climate change and summer mass tourism: the case of Spanish domestic tourism. *Climatic Change,* , 1-13.
Burby, J.R., 2006: Hurricane Katrina and the paradoxes of government disaster policy: bringing about wise governmental decisions for hazardous areas. *The ANNALS of the American Academy of Political and Social Science,* **604**, 171-191.
Buzinde, C.N., D. Manuel-Navarrete, D. Kerstetter, and M. Redclift, 2010a: Representations and adaptation to climate change. *Annals of Tourism Research,* **37(3)**, 581-603.
Buzinde, C.N., D. Manuel-Navarrete, E.E. Yoo, and D. Morais, 2010b: Tourists' perceptions in a climate of change: Eroding Destinations. *Annals of Tourism Research,* **37(2)**, 333-354.
Bye, T., A. Bruvoll, and F.R. Aune, 2006: The Importance of Volatility in a Deregulated Hydro-Dominated Power Market. *Discussion Papers,* **472**.
Callaway, J. M., Louw, D. B., & Hellmuth, M. (2012). Benefits and costs of measures for coping with water and climate change: Berg River Basin, South Africa. Chapter 3 in Climate Change Adaptation in the Water Sector, Kabat, P., Ludwig, F., van der van der Valk, M., & van van Schaik, H. (Eds.). (2012).. Routledge.pp. 205.
Calzadilla, A., K. Rehdanz, and R.S.J. Tol, 2011: Trade Liberalization and Climate Change: A CGE Analysis of the Impacts on Global Agriculture. *Water,* **3(2)**, 526-550.
Candel, F.M., 2007: Climate change and the global insurance industry: impacts and problems in Latin America. *The Geneva Papers,* **32**, 29-34.
Carter, M.R., P.D. Little, T. Mogues, and W. Negatu, 2007: Poverty Traps and Natural Disasters in Ethiopia and Honduras. *World Development*, **35(5)**, 835-856.
Cavan, G., J.F. Handley, J. Aylen, K. Albertson, J. McMorrow, S. Lindley, and D. McEvoy, 2006: Climate change and the visitor economy in the uplands. *International Journal of Biodiversity Science and Management,* **2(3)**, 170-173.
CCSP, 2007: *Effects of Climate Change on Energy Production and Use in the United States. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.* US Department of Energy, Office of Biological & Environmental Research, Washington, D.C., USA.
CCTF, 2008: *Chicago Climate Action Plan: Our City, Our Future.* Chicago Climate Task Force.
Ceron, J.-. and G. Dubois, 2005: The potential impacts of climate change on French tourism. *Current Issues in Tourism,* **8(2-3)**, 125-139.
Changnon, S.A., 2007: Catastrophic winter storms: an escalating problem. *Climatic Change,* **84**, 131-139.
Changnon, S.A., 2008: Assessment of flood losses in the United States. *Journal of Contemporary Water Research & Education,* **138**, 38-44.
Changnon, S.A., 2009a: Characteristics of severe Atlantic hurricanes in the United States: 1949-2006. *Natural Hazards,* **48**, 329-337.
Changnon, S.A., 2009b: Increasing major hail losses in the U.S.. *Climatic Change,* **96**, 161-166.

Changnon, S.A., 2005: Economic impacts of climate conditions in the United States: Past, present, and future - An editorial essay. *Climatic Change,* **68(1-2)**, 1-9.
Chapman, L., 2007: Transport and Climate Change: A Review. *Journal of Transport Geography,* **15**, 354-367.
Charpentier, A., 2008: Insurability of climate risks. *The Geneva Papers,* **33**, 91-109.
Chen, C.-., D. Gillig, and B.A. McCarl, 2001: Effects of climatic change on a water dependent regional economy: A study of the Texas Edwards Aquifer. *Climatic Change,* **49(4)**, 397-409.
Cheng, C.S., Q. Li, G. Li, and H. Auld, 2012: Climate Change and Heavy Rainfall-Related Water Damage Insurance Claims and Losses in Ontario, Canada. *Journal of Water Resource and Protection,* **4(2)**, 49-62 (Doi: 10.4236/jwarp.2012.42007).
Chinowsky, P., K.M. Strzepek, P. Larsen, and A. Opdahl, 2010: Adaptive Climate Response, 2010Cost Models for Infrastructure. *ASCE Journal of Infrastructure Systems,* **16**, 173-181.
Chinowsky, P., C. Hayles, A. Schwwikert, N. Strzepek, K.M. Strzepek, and C.A. Schlosser, 2011: Climate Change: Comparative Impact on Developing and Developed Countries. *The Engineering Project Organization Journal,* **1(1)**, 67-80.
Choi, O. and A. Fisher, 2003: The impacts of socioeconomic development and climate change on severe weather catastrophe losses: Mid-Atlantic Region (MAR) and the U.S. *Climatic Change,* **58(1-2)**, 149-170.
Christensen, J.H. and A. Busuioc, 2007: Regional Climate Projections. *Alfred-Wegener-Institute for Polar and Marine Research,* .
Ciscar, J.-., A. Iglesias, L. Feyen, L. Szabó, D. Van Regemorter, B. Amelung, R. Nicholls, P. Watkiss, O.B. Christensen, R. Dankers, L. Garrote, C.M. Goodess, A. Hunt, A. Moreno, J. Richards, and A. Soria, 2011: Physical and economic consequences of climate change in Europe. *Proceedings of the National Academy of Sciences of the United States of America,* **108(7)**, 2678-2683.
Clarke, D.J. and D. Grenham, 2012: Microinsurance and natural disasters: challenges and options. *Environmental Science & Policy,* (Doi: 10.1016/j.envsci.2012.06.005).
Coble, K.H., T.O. Knight, R.D. Pope, and J.R. Williams, 1997: An expected-indemnity approach to the measurement of moral hazard in crop insurance. *American Journal of Agricultural Economics,* **79**, 216-226.
Collier, B., J. Skees, and B. Barnett, 2009: Weather index insurance and climate change: opportunities and challenges in lower income countries. *The Geneva Papers,* **34**, 401-424.
Coombes, E.G., A.P. Jones, and W.J. Sutherland, 2009: The implications of climate change on Coastal visitor numbers: A regional analysis. *Journal of Coastal Research,* **25(4)**, 981-990.
Corti, T., V. Muccione, P. Köllner-Heck, D. Bresch, and S.I. Seneviratne, 2009: Simulating past droughts and associated building damages in France. *Hydrology and Earth System Sciences,* **13**, 1739-1747.
Courbage, C., M. Orie, and W.R. Stahel, 2012: 2011 Thai floods and insurance. In: *The Geneva Reports - Risk and Insurance Research No. 5. Extreme events and insurance: 2011 annus horribilis.* [Courbage, C. and W.R. Stahel(eds.)]. The Geneva Association, Geneva, pp. 121-132.
Crompton, R.P. and K.J. McAneney, 2008: Normalised Australian insured losses from meteorological hazards: 1967-2006. *Environmental Science & Policy,* **11**, 371-378.
Cruz, A.M. and E. Krausmann, 2013: Vulnerability of the Oil and Gas Sector to Climate Change and Extreme Weather Events. *Forthcoming,* .
Cummins, J.D. and O. Mahul, 2009: *Catastrophe risk financing in developing countries: principles for public intervention.* The World Bank, Washington D.C., pp. 256.
Cummins, J.D. and M.A. Weiss, 2009: Convergence of insurance and financial markets: hybrid and securitized risk-transfer solutions. *The Journal of Risk and Insurance,* **76(3)**, 493-545.
Cummins, J.D., 2012: CAT bonds and other risk-linked securities: product design and evolution of the market. In: *The Geneva Reports - Risk and Insurance Research No. 5. Extreme events and insurance: 2011 annus horribilis.* [Courbage, C. and W.R. Stahel(eds.)]. The Geneva Association (The International Association for the Study of Insurance Economics), Geneva, pp. 39-61.
Dailey, P., M. Huddleston, S. Brown, and D. Fasking, 2009: *The financial risks of climate change: examining the financial implications of climate change using climate models and insurance catastrophe risk models.* In: Report by AIR Worldwide Corp. and the Met Office. The Association of British Insurers, London, pp. 107.
Darwin, R.F. and D. Kennedy, 2000: Economic effects of CO_2 fertilization of crops: transforming changes in yield into changes in supply. *Environmental Modeling and Assessment,* **5**, 157-168.
Darwin, R.F. and R.S.J. Tol, 2001: Estimates of the Economic Effects of Sea Level Rise. *Environmental and Resource Economics,* **19(2)**, 113-129.

Darwin, R.F., 2004: Effects of Greenhouse Gas Emissions on World Agriculture, Food Consumption, and Economic Welfare. *Climatic Change*, **66(1-2)**, 191-238.
Dasgupta, S., Huq, M., Khan, Z. H., Ahmed, M. M. Z., Mukherjee, N., Khan, M., & Pandey, K. (2010). Vulnerability of bangladesh to cyclones in a changing climate: potential damages and adaptation cost. *World Bank Policy Research Working Paper Series, Vol*.5280
Daugherty, D.J., D.L. Buckmeier, and P.K. Kokkanti, 2011: Sensitivity of recreational access to reservoir water level variation: An approach to identify future access needs in reservoirs. *North American Journal of Fisheries Management*, **31(1)**, 63-69.
Dawson, J., D. Scott, and G. Mcboyle, 2009: Climate change analogue analysis of ski tourism in the northeastern USA. *Climate Research*, **39(1)**, 1-9.
Dawson, J. and D. Scott, 2010: Climate change and tourism in the great lakes region: A summary of risks and opportunities. *Tourism in Marine Environments*, **6(2-3)**, 119-132.
Dawson, J. and D. Scott, 2013: Managing for climate change in the alpine ski sector. *Tourism Management*, **35**, 244-254.
Day, J., N. Chin, S. Sydnor, and K. Cherkauer, 2013: Weather, climate, and tourism performance: A quantitative analysis. *Tourism Management Perspectives*, **5**, 51-56.
De Bruin, K., R.B. Dellink, A. Ruijs, L. Bolwidt, A. Van Buuren, J. Graveland, R.S. De Groot, P.J. Kuikman, S. Reinhard, and R.P. Roetter, 2009: Adapting to climate change in The Netherlands: an inventory of climate adaptation options and ranking of alternatives. *Climatic Change*, **95(1)**, 23-45.
De Freitas, C.R., D. Scott, and G. McBoyle, 2008: A second generation climate index for tourism (CIT): Specification and verification. *International Journal of Biometeorology*, **52(5)**, 399-407.
Dell, J.J. and P. Pasteris, 2010: Adaptation in the Oil and Gas Industry to Projected Impacts of Climate Change. **(SPE 126307)**.
Dell, M., B.F. Jones, and B.A. Olken, 2009: Temperature and income: Reconciling new cross-sectional and panel estimates. *American Economic Review*, **99(2)**, 198-204.
Dell, M., B.F. Jones, and B.A. Olken, 2012: Temperature Shocks and Economic Growth: Evidence from the Last Half Century. *American Economic Journal: Macroeconomics*, **4(3)**, 66-95.
Dempson, J.B., M.F. O'Connell, and N.M. Cochrane, 2001: Potential impact of climate warming on recreational fishing opportunities for Atlantic salmon, Salmo salar L., Newfoundland, Canada. *Fisheries Management and Ecology*, **8(1)**, 69-82.
Denstadli, J.M., J.K.S. Jacobsen, and M. Lohmann, Tourist perceptions of summer weather in Scandinavia. *Annals of Tourism Research*, .
Devitt, C. and R.S.J. Tol, 2012: Civil war, climate change, and development: A scenario study for sub-saharan Africa. *Journal of Peace Research*, **49(1)**, 129-145.
DOE, 2007: *Concentrating solar power commercial application study: Reducing water consumption of concentrating solar power electricity generation.* U.S. Department of energy (DOE), Washington D.C., USA.
DOE, 2009: An Analysis of the Effects of Drought Conditions on Electric Power Generation in the United States. *National Energy Technology Laboratory*, **1365**.
Donat, M.G., G.C. Leckebusch, S. Wild, and U. Ulbrich, 2011: Future changes in European winter storm losses and extreme wind speeds detected from GCM and RCM multi-model simulations. *Natural Hazards and Earth System Sciences*, **11**, 1351-1370.
Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas, 2009: Ocean acidification: The other CO 2 problem. *Annual Review of Marine Science*, **1**, 169-192.
Dore, M. and I. Burton, 2001: *The Costs of Adaptation to Climate Change in Canada: A Stratified Estimate by Sectors and Regions – Social Infrastructure.* Climate Change Laboratory, Brock University, St Catharines, Canada, pp. 117.
DOT, 2002: Federal Research Partnership Workshop. In: *The Potential Impacts of Climate Change on Transportation* Department of Transportation Center for Climate Change and Environmental Forecasting., .
Droogers, P., 2009: Climate Change and Hydropower, Impact and Adaptation Costs: Case Study Kenya. *FutureWater*, .
Duus-Otterström, G. and S.C. Jagers, 2011: Why (most) climate insurance schemes are a bad idea. *Environmental Politics*, **20(3)**, 322-339 (Doi:10.1080/09644016.2011.573354).
Easterly, W. and R. Levine, 2003: Tropics, germs, and crops: how endowments influence economic development. *Journal of Monetary Economics*, **50(1)**, 3-39.

Ebert, I., 2010: Legal aspects of U.S. claims based on greenhouse gas emissions. In: *Liability for climate change? Experts' views on a potential emerging risk.* [Munich Re (ed.)]. Munich Re, Munich, pp. 14-15.
Ebinger, J. and W. Vergara, 2011: *Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation.* The World Bank, Washington, D.C., USA., .
Eboli, F., R. Parrado, and R. Roson, 2010a: Climate-change feedback on economic growth: Explorations with a dynamic general equilibrium model. *Environment and Development Economics,* **15(5)**, 515-533.
Eboli, F., R. Parrado, and R. Roson, 2010b: Climate-change feedback on economic growth: Explorations with a dynamic general equilibrium model. *Environment and Development Economics,* **15(5)**, 515-533.
Eide, A. and K. Heen, 2002: Economic impacts of global warming. A study of the fishing industry in North Norway. *Fisheries Research*, **56(3)**, 261-274.
Eide, A., 2008: An integrated study of economic effects of and vulnerabilities to global warming on the Barents Sea cod fisheries. *Climatic Change,* **87(1-2)**, 251-262.
Eijgelaar, E., C. Thaper, and P. Peeters, 2010: Antarctic cruise tourism: The paradoxes of ambassadorship, "last chance tourism" and greenhouse gas emissions. *Journal of Sustainable Tourism,* **18(3)**, 337-354.
Elsasser, H. and R. Bürki, 2002: Climate change as a threat to tourism in the Alps. *Climate Research,* **20(3)**, 253-257.
Emanuel, K., 2011: Global warming effects on U.S. hurricane damage. *Weather, Climate and Society,* **3(4)**, 261-268.
Endler, C. and A. Matzarakis, 2010a: Climatic potential for tourism in the Black Forest, Germany - winter season. *International Journal of Biometeorology,* , 1-13.
Endler, C. and A. Matzarakis, 2010b: Analysis of high-resolution simulations for the Black Forest region from a point of view of tourism climatology - a comparison between two regional climate models (REMO and CLM). *Theoretical and Applied Climatology,* , 1-14.
Endler, C., K. Oehler, and A. Matzarakis, 2010: Vertical gradient of climate change and climate tourism conditions in the Black Forest. *International Journal of Biometeorology,* **54(1)**, 45-61.
Endler, C. and A. Matzarakis, 2011: Climate and tourism in the Black Forest during the warm season. *International Journal of Biometeorology*, **55(2)**, 173-186.
EPA , U.S., 2001: Technical Development Document for the Final Regulations Addresing cooling water Intake Structures for the New Facilities. *Office of Water,* **United States Environmental Protection Agency**.
Falk, M., 2013: Impact of Long-Term Weather on Domestic and Foreign Winter Tourism Demand. *International Journal of Tourism Research,* **15(1)**, 1-17.
Fankhauser, S. and R.S.J. Tol, 2005: On climate change and economic growth. *Resource and Energy Economics,* **27(1)**, 1-17.
Fant, C., Gebretsadik Y., and K.M. Strzepek, 2012: *Uncertainty Approach to Climate Change Impacts on the Hydropower of the Zambezi Basin* Review of International Economics, .
Farbotko, C., 2010: 'The global warming clock is ticking so see these places while you can': Voyeuristic tourism and model environmental citizens on Tuvalu's disappearing islands. *Singapore Journal of Tropical Geography,* **31(2)**, 224-238.
Faure, M.G. and M. Peeters (eds.), 2011: *Climate change liability.* Elgar, Cheltenham, pp. 304.
Feeley III, T.J., T.J. Skone, G.J. Stiegel Jr, A. McNemar, M. Nemeth, B. Schimmoller, J.T. Murphy, and L. Manfredo, 2008: Water: A critical resource in the thermoelectric power industry. *Energy,* **33(1)**, 1-11.
Feyen, L., R. Dankers, K. Bódis, P. Salamon, and J.I. Barredo, 2012: Fluvial flood risk in Europe in present and future climates. *Climatic Change,* **112(1)**, 47-62.
FHWA, 2006: Long-Term Pavement Performance (LTPP) Data Analysis Support: National Pooled Fund Study TPF-5(013) - Effects of Multiple Freeze Cycles and Deep Frost Penetration on Pavement Performance and Cost. *FHWA,* **FHWA-HRT-06-121**.
Floc'h, P.L., J.-. Poulard, O. Thébaud, F. Blanchard, J. Bihel, and F. Steinmetz, 2008: Analyzing the market position of fish species subject to the impact of long-term changes: A case study of French fisheries in the Bay of Biscay. *Aquatic Living Resources,* **21(3)**, 307-316.
Ford, J.D., T. Pearce, J. Prno, F. Duerden, L.B. Ford, M. Beaumier, and T. Smith, 2010: Perceptions of climate change risks in primary resource use industries: A survey of the Canadian mining sector. *Regional Environmental Change,* **10(1)**, 65-81.

Ford, J.D., T. Pearce, J. Prno, F. Duerden, L. Berrang Ford, T.R. Smith, and M. Beaumier, 2011: Canary in a coal mine: perceptions of climate change risks and response options among Canadian mine operations. *Climatic Change*, , 1-17.
Førland, E.J., J.K. Steen Jacobsen, J.M. Denstadli, M. Lohmann, I. Hanssen-Bauer, H.O. Hygen, and H. Tømmervik, 2012: Cool weather tourism under global warming: Comparing Arctic summer tourists' weather preferences with regional climate statistics and projections. *Tourism Management*, .
Förster, H. and J. Lilliestam, 2009: Modeling thermoelectric power generation in view of climate change. *Regional Environmental Change*, , 1-12.
Forster, J., P.W. Schuhmann, I.R. Lake, A.R. Watkinson, and J.A. Gill, 2012: The influence of hurricane risk on tourist destination choice in the Caribbean. *Climatic Change*, **114(3-4)**, 745-768.
Fortier, A., D. Sarrazin, F. Calmels, D. Fortier, D. Chaumont, J.P. Savard, and Tarussov A., *L'impact du Réchauffement Climatique sur les Aéroports due Nunavik: Caractéristiques du Pergélisol et Caractérisation des Processus de Dégradation des Pistes.* Natural Resources Canada.
Gabrielsen, K., T. Bye, and F.R. Aune, 2005: Climate Change-Lower Electricity Prices and Increasing Demand: An Application to the Nordic Countries. *Discussion Papers in Research Department of Statistics Norway*, **No. 430**.
Gall, M., K.A. Borden, C.T. Emrich, and S.L. Cutter, 2011: The Unsustainable Trend of Natural Hazard Losses in the United States. *Sustainability*, **3(11)**, 2157-2181 (Doi:10.3390/su3112157).
Gallup, J.L., J.D. Sachs, and A.D. Mellinger, 1999: Geography and Economic Development. *International Regional Science Review*, **22(2)**, 179-232.
Galor, O. and D.N. Weil, 1996: The Gender Gap, Fertility, and Growth. *American Economic Review*, **86(3)**, 374-387.
GAO, 2010: *National flood insurance program: continued actions needed to address financial and operational issues.*[Testimony before the Commitee on Banking, Housing, and Urban Affairs, U.S. Senate, GAO-10-1063T (ed.)]. United States Government Accountability Office (GAO), pp. 1-22.
GAO, 2011: *Flood insurance: public policy goals provide a framework for reform.*[Testimony before the Subcommittee on Insurance, Housing, and Community Opportunity, Committee on Financial Services, House of Representatives, GAO-11-429T (ed.)]. United States Government Accountability Office (GAO), pp. 1-15.
Garvey, S.D., 2010: Structural Capacity and the 20 MW Wind Turbine. *Proceedings of the Institution of Mechanical Engineers Part a-Journal of Power and Energy*, **224**, 1083-1115.
Garza-Gil, M.D., J. Torralba-Cano, and M.M. Varela-Lafuente, 2011: Evaluating the economic effects of climate change on the European sardine fishery. *Regional Environmental Change*, **11(1)**, 87-95.
German Insurance Association, 2011: *The climate change challenge. Answers and demands of German insurers.* German Insurance Association, Berlin, pp. 20pp.
Gerrard, B.G. (ed.), 2007: *Global climate change and U.S. law.* American Bar Association, Chicago, pp. 784.
Gerstengarbe, F.-., P.C. Werner, H. Österle, and O. Burghoff, 2013: Winter storm- and summer thunderstorm-related loss events with regard to climate change in Germany. *Theoretical and Applied Climatology*, (Doi: 10.1007/s00704-013-0843-y).
Ghesquiere, F. and O. Mahul, 2007: Sovereign natural disaster insurance for developing countries: a paradigm shift in catastrophe risk financing. *The World Bank Policy Research Working Paper, 4345*, , 1-24.
Giannakopoulos, C., E. Kostopoulou, K.V. Varotsos, K. Tziotziou, and A. Plitharas, 2011: An integrated assessment of climate change impacts for Greece in the near future. *Regional Environmental Change*, , 1-15.
Gibbons, J.H., 2012: Technology and Innovation. In: *Energy for development: Resources, technologies, environment.* [Toth, F.L. (ed.)]. Kluwer, Dordrecht, pp. 141-148.
Ginsburgh, V. and M.A. Keyzer, 1997: *The Structure of Applied General Equilibrium Models.* The MIT Press, Cambridge, pp. 555.
Glauber, J.W., 2004: Crop insurance reconsidered. *American Journal of Agricultural Economics*, **86(5)**, 1179-1195.
Gollin, D. and C. Zimmermann, 2008: *Malaria: Disease Impacts and Long-Run Income Differences.* Economics Department, Williams College, Williamstown.
Gollin, D. and C. Zimmermann, 2010: *Global Climate Change and the Resurgence of Tropical Disease: An Economic Approach.* Economics Department, Williams College, Williamstown.
Golombek, R., S.A.C. Kittelsen, and I. Haddeland, 2011: Climate change: Impacts on electricity markets in Western Europe. *Climatic Change*, **(113)**, 357-370.
Gómez-Martín, M.B., 2006: *Climate potential and tourist demand in Catalonia (Spain) during the summer season* pp. 75-87.

Gössling, S., M. Bredberg, A. Randow, E. Sandström, and P. Svensson, 2006: Tourist perceptions of climate change: A study of international tourists in Zanzibar. *Current Issues in Tourism*, **9(4-5)**, 419-435.

Gössling, S. and C.M. Hall, 2006: Uncertainties in predicting tourist flows under scenarios of climate change. *Climatic Change*, **79(3-4)**, 163-173.

Gössling, S., D. Scott, C.M. Hall, J.-. Ceron, and G. Dubois, 2012: Consumer behaviour and demand response of tourists to climate change. *Annals of Tourism Research*, **39(1)**, 36-58.

Grace, M.F. and R.W. Klein, 2009: The perfect storm: hurricanes, insurance, and regulation. *Risk Management and Insurance Review*, **12(1)**, 81-124.

Graff Zivin, J. and M.J. Neidell, 2010: *Temperature and the Allocation of Time: Implications for Climate Change.* In: Working Paper. National Bureau of Economic Research, Washington, D.C., pp. 1-41.

Grey, D. and C.W. Sadoff, 2007: Sink or Swim? Water security for growth and development. *Water Policy*, **9(6)**, 545-571.

Gunnar, S.E. and K.M. Torben, 2010: Electricity Demand in a Changing Climate. *Mitigation and Adaptation Strategies for Global Change*, **15(8)**, 877-897.

Guy Carpenter, 2011: *Points of inflection - positioning for change in a challanging market.* In: Global Reinsurance Outlook. Guy Carpenter & Company LLC., pp. 72.

Hall, C.M., 2006: New Zealand tourism entrepreneur attitudes and behaviours with respect to climate change adaptation and mitigation. *International Journal of Innovation and Sustainable Development*, **1(3)**, 229-237.

Hall, J.W., P.B. Sayers, and R.J. Dawson, 2005: National-scale assessment of current and future flood risk in England and Wales. *Natural Hazards*, **36(1-2)**, 147-164.

Hallegatte, S., 2005: The long time scales of the climate-economy feedback and the climatic cost of growth. *Environmental Modeling and Assessment*, **10(4)**, 277-289.

Hallegatte, S. and D. Thery, 2007: Are the economic impacts of climate change underestimated? *Revue d'Economie Politique*, **117(4)**, 507-522.

Hallegatte, S. and M. Ghil, 2008: Natural disasters impacting a macroeconomic model with endogenous dynamics. *Ecological Economics*, **68(1-2)**, 582-592.

Hallegatte, S. and P. Dumas, 2009: Can natural disasters have positive consequences? Investigating the role of embodied technical change. *Ecological Economics*, **68(3)**, 777-786.

Hamilton, J.M., D.J. Maddison, and R.S.J. Tol, 2005a: Effects of climate change on international tourism. *Climate Research*, **29(3)**, 245-254.

Hamilton, J.M., D.J. Maddison, and R.S.J. Tol, 2005b: Climate change and international tourism: A simulation study. *Global Environmental Change*, **15(3)**, 253-266.

Hamilton, J.M., 2007: Coastal landscape and the hedonic price of accommodation. *Ecological Economics*, **62(3-4)**, 594-602.

Hamilton, J.M. and R.S.J. Tol, 2007: The impact of climate change on tourism in Germany, the UK and Ireland: A simulation study. *Regional Environmental Change*, **7(3)**, 161-172.

Hamilton, L.C., C. Brown, and B.D. Keim, 2007: Ski areas, weather and climate: Time series models for New England case studies. *International Journal of Climatology*, **27(15)**, 2113-2124.

Hamzah, J., A. Habibah, A. Buang, K. Jusoff, M.E. Toriman, M.J. Mohd. Fuad, A.C. Er, and A.M. Azima, 2012: Flood disaster, impacts and the tourism providers' responses: The Kota Tinggi experience. *Advances in Natural and Applied Sciences*, **6(1)**, 26-32.

Harrison, S.J., S.J. Winterbottom, and C. Sheppard, 1999: The potential effects of climate change on the Scottish tourist industry. *Tourism Management*, **20(2)**, 203-211.

Hattermann, F.F., S. Huang, O. Burghoff, W. Willems, H. Österle, M. Büchner, and Z. Kundzewisz, planned 2013: Modelling flood damages under climate change - a case study for Germany. *Submitted Paper*, .

Haug, O., X.K. Dimakos, J.F. Vardal, M. Aldrin, and E. Meze-Hausken, 2011: Future building water loss projections posed by climate change. *Scandinavian Actuarial Journal*, **1**, 1-20 (Doi:10.1080/03461230903266533).

Haugen, J.E. and T. Iversen, 2008: Response in extremes of daily precipitation and wind from a downscaled multi model ensemble of anthropogenic global climate change scenarios. *Tellus A*, **60(3)**, 411-426.

Hecht, S.B., 2008: Climate change and the transformation of risk: insurance matters. *UCLA Law Review*, **55**, 1559-1620.

Hein, L., M.J. Metzger, and A. Moreno, 2009: Potential impacts of climate change on tourism; a case study for Spain. *Current Opinion in Environmental Sustainability*, **1(2)**, 170-178.

Heintz, J.E., M.H. Kanemitsu, and E. Scanlan, 2009: Insurance coverage for climate change suits: the battle has begun. *Environmental Claims Journal*, **21(1)**, 29-51.
Held, H., F.-. Gerstengarbe, T. Pardowitz, J.F. Pinto, U. Ulbrich, U. Böhm, K. Born, Büchner,M.,Donat,M.G., M.K. Karremann, G.C. Leckebusch, P. Ludwig, K.M. Nissen, T. Nocke, H. Österle, B.F. Prahl, P.C. Werner, and O. Burghoff, planned 2013: Projections of global warming-induced impacts on winter storm losses in the German private household sector. *Submitted Paper,* .
Hendrikx, J. and E.Ö. Hreinsson, 2012: The potential impact of climate change on seasonal snow in New Zealand: Part II-industry vulnerability and future snowmaking potential. *Theoretical and Applied Climatology,* **110(4)**, 619-630.
Hendrikx, J., E.Ö. Hreinsson, M.P. Clark, and A.B. Mullan, 2012: The potential impact of climate change on seasonal snow in New Zealand: Part I-an analysis using 12 GCMs. *Theoretical and Applied Climatology,* **110(4)**, 607-618.
Herbold, J., planned 2013: Finance for food - towards new agricultural and rural finance. In: *Finance for food.* [Köhn, D. (ed.)]. Springer, Heidelberg, .
Herweijer, C., N. Ranger, and R.E.T. Ward, 2009: Adaptation to climate change: threats and opportunities for the insurance industry. *The Geneva Papers,* **34**, 360-380.
Hess, U. and P. Hazell, 2009: Sustainability and scalability of index-based insurance for agriculture. In: *Innovations in insuring the poor.* [Vargas Hill, R. and M. Torrero(eds.)]. The International Food Policy Research Institute, Washington, DC, pp. 13-14.
Hill, M., A. Wallner, and J. Furtado, 2010: Reducing vulnerability to climate change in the Swiss Alps: A study of adaptive planning. *Climate Policy,* **10(1)**, 70-86.
Hines, P., J. Apt, and S. Talukdar, 2009: Large blackouts in North America: Historical trends and policy implications. *Energy Policy,* **37(12)**, 5249-5259.
Hochrainer, S., R. Mechler, and D. Kull, 2010: Micro-insurance against drought risk in changing climate. Assessing demand and supply considerations. *International Journal of Climate Strategies and Management,* **2(2)**, 148-166.
Hochrainer, S. and R. Mechler, 2011: Natural disaster risk in Asian megacities: a case for risk pooling? *Cities,* **28**, 53-61.
Hoffmann, B., U. Müller, S. Häfele, and U. Karl, 2010: Analysis of the impact of changing hydro-meteorological parameters on the electricity production of once-through cooled thermal power plants in Germany-A System Dynamics modelling approach.Proceedings of International Conference on Energy, Environment and Health – Optimisation of Future Energy Systems, Copenhagen, Denmark, pp. 33.
Hoffmann, V.H., D.C. Sprengel, A. Ziegler, M. Kolb, and B. Abegg, 2009: Determinants of corporate adaptation to climate change in winter tourism: An econometric analysis. *Global Environmental Change,* **19(2)**, 256-264.
Honeyborne, R., 2009: Flat plate versus evacuated tube solar collectors. *International Technology Sourcing,* .
Hopkins, D., J.E.S. Higham, and S. Becken, 2012: Climate change in a regional context: relative vulnerability in the Australasian skier market. *Regional Environmental Change,* , 1-10.
Horowitz, J.K., 2009: The income-temperature relationship in a cross-section of countries and its implications for predicting the effects of global warming. *Environmental and Resource Economics,* **44(4)**, 475-493.
Hsiang, S.M., 2010: Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. *Proceedings of the National Academy of Sciences of the United States of America,* **107(35)**, 15367-15372.
Hübler, M., G. Klepper, and S. Peterson, 2008: Costs of climate change. The effects of rising temperatures on health and productivity in Germany. *Ecological Economics,* **68(1-2)**, 381-393.
Huebner, A., 2012: Public perceptions of destination vulnerability to climate change and implications for long-haul travel decisions to small island states. *Journal of Sustainable Tourism,* **20(7)**, 939-951.
Hughes, G., P. Chinowsky, and K. Strzepek, 2010: The costs of adaptation to climate change for water infrastructure in OECD countries. *Utilities Policy,* **18(3)**, 142-153.
Hunt, A. and P. Watkiss, 2010: Climatic Change Impacts and Adaptation in Cities: A Review of the Literature. *Climatic Change,* .
Hurd, B.H., M. Callaway, J. Smith, and P. Kirshen, 2004: *Climatic change and u.s. Water resources: from modeled watershed impacts to national estimates*. *Journal of the American Water Resource Association,* **40(1)**, 129-148.
Hutton, G., 2011: The economics of health and climate change: Key evidence for decision making. *Globalization and Health,* **7**.

IAEA (International Atomic Energy Agency), 2011: *Core Knowledge on Instrumentation and Control Systems in Nuclear Power Plants.* IAEA, Vienna, Austria, .

Ibarra, E.M., 2011: The use of webcam images to determine tourist-climate aptitude: Favourable weather types for sun and beach tourism on the Alicante coast (Spain). *International Journal of Biometeorology,* **55(3)**, 373-385.

IEA, 2008: *World Energy Outlook 2008.* Organization for Economic Cooperation and Development/International Energy Agency, Paris, France, .

IEA, 2010aa: *World Energy Outlook 2010.* Organization for Economic Cooperation and Development/International Energy Agency, Paris, France, .

IEA, 2010ab: *World Energy Outlook 2009.* Organization for Economic Cooperation and Development/International Energy Agency, Paris, France, .

IEA, 2010b: *Energy Technology Perspectives 2010.* Organization for Economic Cooperation and Development/International Energy Agency, Paris, France, .

IEA, 2012: *World Energy Outlook 2012.* Organization for Economic Development and Cooperation/International Energy Agency, Paris, France, .

Iizumi, T., M. Yokozawa, Y. Hayashi, and F. Kimura, 2008: Climate change impact on rice insurance payouts in Japan. *Journal of Applied Meteorology and Climatology,* **47**, 2265-2278.

Ikefuji, M., J. Magnus, and H. Sakamoto, 2010: *Climate Change, Economic Growth, and Health.* Osaka, Institute of Social and Economic Research, Osaka University.

Ikefuji, M. and R. Horii, 2012: Natural disasters in a two-sector model of endogenous growth. *Journal of Public Economics,* **96(9-10)**, 784-796.

IPCC, 2005: *Carbon Dioxide Capture and Storage.* IPCC Special Report. Cambridge University Press, Cambridge, UK.

IPCC, 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* [Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-., Allen, S.K., Tignor, M. and Midgley, P.M. (eds.)]. Cambridge University Press, Cambridge, UK, and New York, USA, pp. 582pp.

Isaac, M. and D. Van Vuuren, 2009: Modelling Global Residential Sector Energy Demand for Heating and Air Conditioning in the Context of Climate Change *Energy Policy,* **37**, 507-521.

Jiang, M., E. Wong, L.M. Klint, T. DeLacy, and D. Dominey-Howes, 2012: Tourism adaptation to climate change-analysing the policy environment of Fiji. *International Journal of Tourism Policy,* **4(3)**, 238-260.

Jochem, E.S., T. Barker, G. Catenazzi, W. Eichhammer, T. Fleiter, A. Held, N. Helfrich, M. Jakob, P. Criqui, S. Mima, L. Quandt, A. Peters , M. Ragwitz, U. Reiter, F. Reitze, M. Schelhaas, S. Scrieciu, and H. Turton, 2009: Report of the reference and 2°C scenario for Europe. Deliverable D-M1.2 of ADAM (Adaptation and Mitigation Strategies: Supporting European Climate Policy). *Fraunhofer Institute for Systems and Innovation Research (ISI),* .

Jones, B., D. Scott, and H.A. Khaled, 2006: Implications of climate change for outdoor event planning: A case study of three special events in Canada's National Capital Region. *Event Management,* **10(1)**, 63-76.

Jones, B.F. and B.A. Olken, 2010: Climate shocks and exports. *American Economic Review,* **100(2)**, 454-459.

Jopp, R., T. DeLacy, J. Mair, and M. Fluker, 2013: Using a Regional Tourism Adaptation Framework to Determine Climate Change Adaptation Options for Victoria's Surf Coast. *Asia Pacific Journal of Tourism Research,* **18(1-2)**, 144-164.

Jorgenson, D., R. Goettle, B. Hurd, and J. and Smith, 2004: U.S. Market Consequences of Global Climate Change.

Kabat, P., H. van Schaik, and B. Appleton, 2003: *Climate changes the water rules: How water managers can cope with today's climate variability and tomorrow's climate change.* Dialouge on Water and Climate, The Netherlands, pp. 105. http://www.waterandclimate.org/UserFiles/File/changes.pdf.

Kane, S., J.M. Reilly, and J. Tobey, 1992: An Empirical Study of the Economic Effects of Climate Change on World Agriculture. *Climatic Change,* **21(1)**, 17-35.

Kemfert, C., 2002: An Integrated Assessment Model of Economy-Energy-Climate – The Model Wiagem. *Integrated Assessment,* **3(4)**, 281-298.

Khosla, V., 2008: *Scalable Electric Power from Solar Energy.* The Climate Group, Brussels, Belgium.

Kingwell, R. and I. Farré, 2009: Climate change impacts on investment in crop sowing machinery. *Australian Journal of Agricultural and Resource Economics,* **53(2)**, 265-284.

Kirkinen, J., A. Martikainen, H. Holttinen, I. Savolainen, O. Auvinen, and S. Syri, 2005: Impacts on the energy sector and adaptation of the electricity network business under a changing climate in Finland. *Finnish Environment Institute Mimeographs 340*, **(Working Paper 10)**, 43.
Kirshen, P., 2007. Adaptation options and cost in water supply. Report to the UNFCCC Secretariat Financial and Technical Support Division, http://unfccc.int/cooperation_and_support/financial_mechanism/financial_mechanism_gef/items/4054.php.
Kirshen, P., Ruth, M., Anderson, W., 2005. Responding to climate change in Metropolitan Boston: the role of adaptation. New England Journal of Public Policy, 20(2), 89–104.
Kirshen, P., Ruth, M., Anderson, W., 2006. Climate's long-term impacts on urban infrastructures and services: the case of Metro Boston. In: Ruth, M., Donaghy, K., Kirshen, P.H., (Eds.). Climate Change and Variability: Local Impacts and Responses. Edward Elgar Publishers, Cheltenham, UK., Chapter 7.
Kjellstrom, T., R.S. Kovats, S.J. Lloyd, T. Holt, and R.S. Tol, 2009a: The direct impact of climate change on regional labor productivity *Archives of Environmental & Occupational Health*, **64(4)**, 217-227.
Kjellstrom, T., R.S. Kovats, S.J. Lloyd, T. Holt, and R.S.J. Tol, 2009b: The direct impact of climate change on regional labor productivity. *Archives of Environmental and Occupational Health*, **64(4)**, 217-227.
Klint, L.M., M. Jiang, A. Law, T. DeLacy, S. Filep, E. Calgaro, D. Dominey-Howes, and D. Harrison, 2012: Dive tourism in Luganville, Vanuatu: Shocks, stressors, and vulnerability to climate change. *Tourism in Marine Environments*, **8(1-2)**, 91-109.
Koch, H., S. Vögele, M. Kaltofen, and U. Grünewald, 2012: Trends in Water Availability for Power Plants-Scenario Analyses for the German Capital Berlin. *Climatic Change*, **110(3-4)**, 979-899.
Koetse, M. and P. Rietveld, 2009: The Impact of Climate Change and Weather on Transport: An Overview of Empirical Findings. *Transportation Research Part D*, , 205-221.
Kong, C., J. Bang, and Y. Sugiyama, 2005: Structural Investigation of Composite Wind Turbine Blade Considering Various Load Cases and Fatigue Life. *Energy*, **30**, 2101-2114.
Kousky, C. and H. Kunreuther, 2010: Improving flood insurance and flood-risk management: insights from St. Louis, Missouri. *Natural Hazards Review*, **11(4)**, 162-172.
Kousky, C. and R. Cooke, 2012: Explaining the Failure to Insure Catastrophic Risks. *The Geneva Papers*, **37(2)**, 206-227 (Doi:10.1057/gpp.2012.14).
Kovacevic, R.M. and G.C. Pflug, 2011: Does Insurance help to Escape the Poverty Trap? - A Ruin Theoretic Approach. *The Journal of Risk and Insurance*, **748(4)**, 1003-1027.
Krausmann, E. and F. Mushtaq, 2008: A qualitative Natech damage scale for the impact of floods on selected industrial facilities. *Natural Hazards*, **46(2)**, 179-197.
Kron, W. and G. Berz, 2007: *Flood disasters and climate change: trends and options - a (re-)insurer's view* Hamburg, Germany, pp. 268-273.
Kron, W., 2009: Flood insurance: from clients to global financial markets. *Journal of Flood Risk Management*, **2**, 68-75 (Doi: 10.1111/j.1753-318X.2008.01015.x).
Kron, W., 2012: Changing flood risk - a re-insurer's viewpoint. In: *Changes in flood risk in Europe.* [Kundzewicz, Z.W. (ed.)]. International Association of Hydrological Sciences, Wallingford, UK, pp. 459-490.
Kron, W. and M. Steuer, 2012: Mississippi-Flut 2011 – Erfolgreiches Hochwassermanagement. *Korrespondenz Wasserwirtschaft*, **5**, 245-250 (Doi: 10.3243/kwe2012.05.001).
Kron, W., M. Steuer, P. Loew, and A. Wirtz, 2012: How to deal properly with a natural catastrophe database - analysis of flood losses. *Natural Hazards and Earth System Sciences*, **12**, 535-550.
Kulshreshtha, S.N., 2011: Climate Change, Prairie Agriculture, and Prairie Economy: The New Normal. *Canadian Journal of Agricultural Economics*, **59(1)**, 19-44.
Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P., Kabat, P., Jiménez, B., Miller, K.A., Oki, T., Sen, Z., Shiklomanov, I.A., 2007. Freshwater resources and their management. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., Van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of the Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., pp. 173-210.
Kunreuther, H.C. and E.O. Michel-Kerjan, 2009: The development of new catastrophe risk markets. *Annual Review of Resource Economics*, **1**, 119-139.
Kunreuther, H.C., E.O. Michel-Kerjan, N.A. Doherty, M.R. Grace, R.W. Klein, and M.V. Pauly, 2009: *At war with the weather: managing large-scale risks in a new era of catastrophes.* The Massachusetts Institute of Technology Press, Cambridge, Massachusetts and London, England, pp. 416.

Kunreuther, H.C., E.O. Michel-Kerjan, and N. Ranger, 2012: Insuring future climate catastrophes. *Climatic Change,* (Doi: 10.1007/s10584-012-0625-z).
Kunz, K., J. Sander, and C. Kottmeier, 2009: Recent trends of thunderstorm and hailstorm frequency and their relation to atmospheric characteristics in southwest Germany. *International Journal of Climatology,* **29**, 2283-2297.
Kurtz, S., J. Granata, and M. Quintana, 2009: Photovoltaic Reliability R&D Toward a Solar-Powered World. Paper No. 74120Z. *In: NREL Report No. CP-520-47383* [Dhere, N.G. (ed.)]. Proceedings of Reliability of Photovoltaic Cells, Modules, Components, and Systems II. SPIE - The International Society for Optical Engineering, 3-6 August 2009, San Diego, California, pp. 27-12.
Kurtz, S., K. Whitfield, G. TamizhMani, M. Koehl, D. Miller, J. Joyce, J. Wohlgemuth, N. Bosco, M. Kempe, and T. Zgonena, 2011: Evaluation of high temperature exposure of photovoltaic modules. *Progress in Photovoltaics: Research and Applications,* **19**, 954-965.
Landauer, M., U. Pröbstl, and W. Haider, 2012: Managing cross-country skiing destinations under the conditions of climate change - Scenarios for destinations in Austria and Finland. *Tourism Management*, **33(4)**, 741-751.
Larsen, P., S. Goldsmith, O. Smith, M. Wilson, K. Strezpek, P. Chinowsky, and B. Saylor, 2008: Estimating Future Costs for Alaska Public Infrastructure at Risk from Climate Change. *Global Environmental Change,* **18**, 442-457.
Lavin, P.G., 2003: Asphalt Pavements: A Practical Guide to Design, Production, and Maintenance for Architects and Engineers. *Spon Press,* .
Leblois, A. and P. Quirion, 2011: Review - Agricultural insurances based on meteorological indices: realizations, methods and research challenges. *Meteorological Applications,* (Doi: 10.1002/met.303).
Leckebusch, G.C., U. Ulbrich, L. Fröhlich, and J.G. Pinto, 2007: Property loss potentials for European midlatitude storms in a changing climate. *Geophysical Research Letters,* **34**.
Leckebusch, G.C., A. Weimer, J.G. Pinto, M. Reyers, and P. Speth, 2008: Extreme wind storms over Europe in present and future climate: a cluster analysis approach. *Meteorologische Zeitschrift,* **17(1)**, 67-82.
Lee, D.M. and K.S. Lyon, 2004: A Dynamic Analysis of the Global Timber Market under Global Warming: An Integrated Modeling Approach. *Southern Economic Journal*, **70(3)**, 467-489.
Lee, H.-., 2009: The impact of climate change on global food supply and demand, food prices, and land use. *Paddy and Water Environment*, **7(4)**, 321-331.
Leiva, A.J. and J.R. Skees, 2008: Using irrigation insurance to improve water usage of the Rio Mayo irrigation system in Northwestern Mexico. *World Development*, **36(12)**, 2663-2678.
Lemmen, D. and F. Warren, 2010: *Climate Change Impacts and Adaptation: A Canadian Perspective.* [Lemmen, D. and Warren, F. (eds.)]. Natural Resources Canada.
Leurig, S., 2011: *Climate risk disclosure by insurers: evaluating insurer responses to the NAIC climate disclosure survey*. In: A Ceres Report. Ceres, Boston, pp. 54pp.
Lin, T.-. and A. Matzarakis, 2008: Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. *International Journal of Biometeorology*, **52(4)**, 281-290.
Lin, T.-. and A. Matzarakis, 2011: Tourism climate information based on human thermal perception in Taiwan and Eastern China. *Tourism Management,* **32(3)**, 492-500.
Link, P.M. and R.S.J. Tol, 2009: Economic impacts on key Barents Sea fisheries arising from changes in the strength of the Atlantic thermohaline circulation. *Global Environmental Change*, **19(4)**, 422-433.
Linnerooth-Bayer, J. and R. Mechler, 2009: DESA Working Paper No.85. In: *Insurance against losses from natural disasters in developing countries.*[United Nations, Department of Economic and Social Affairs (UN/DESA) (ed.)]. United Nations, Department of Economic and Social Affairs, New York, http://www.un.org/esa/desa/papers, pp. 35pp.
Linnerooth-Bayer, J., K. Warner, C. Bals, P. Höppe, I. Burton, T. Loster, and A. Haas, 2009: Insurance, developing countries and climate change. *The Geneva Papers,* **34**, 381-400.
Linnerooth-Bayer, J. and R. Mechler, 2011: Insurance against losses from natural disasters in developing countries. Evidence, gaps and the way forward. *Journal of Integrated Disaster Risk Management*, **1(1)**, 1-35.
Linnerud, K., T.K. Mideksa, and G.S. Eskeland, 2011: The impact of climate change on nuclear power supply. *Energy Journal*, **32(1)**, 149-168.
Lise, W. and R.S.J. Tol, 2002: Impact of climate on tourist demand. *Climatic Change,* **55(4)**, 429-449.

Lonfat, M., A. Boissonnade, and R. Muir-Wood, 2007: Atlantic basin, U.S. and Caribbean landfall activity rates over the 2006-2010 period: an insurance industry perspective. *Tellus A*, **59(4)**, 499-510 (DOI:10.1111/j.1600-0870.2007.00242.x).
Maddison, D., 2001: In search of warmer climates? The impact of climate change on flows of British tourists. *Climatic Change*, **49(1-2)**, 193-208.
Mahul, O. and C.J. Stutley, 2010: *Government support to agricultural insurance: challenges and options for developing countries.* The World Bank, Washington D.C., pp. 219.
Makki, S.S. and A. Somwaru, 2001: Evidence of adverse selection in crop insurance markets. *The Journal of Risk and Insurance*, **68(4)**, 685-708.
Mansur, E.T., R.O. Mendelsohn, and W. Morrison, 2005: A Discrete-Continuous Choice Model of Climate Change Impacts on Energy. *Yale SOM Working Paper*, **ES-43**.
Markoff, M.S. and A.C. Cullen, 2008: Impact of Climate Change on Pacific Northwest Hydropower. *Climatic Change*, **87**, 451-469.
Masters, W.A. and M.S. McMillan, 2001: Climate and Scale in Economic Growth. *Journal of Economic Growth*, **6(3)**, 167-186.
Matzarakis, A., M. Hämmerle, C. Endler, S. Muthers, and E. Koch, 2012: Assessment of tourism and recreation destinations under climate change conditions in Austria. *Meteorologische Zeitschrift*, **21(2)**, 157-165.
Matzarakis, A., T. Georgiadis, and F. Rossi, 2007: Thermal bioclimate analysis for Europe and Italy. *Nuovo Cimento Della Societa Italiana Di Fisica C*, **30(6)**, 623-632.
Matzarakis, A. and C. Endler, 2010: Climate change and thermal bioclimate in cities: Impacts and options for adaptation in Freiburg, Germany. *International Journal of Biometeorology*, **54(4)**, 479-483.
Matzarakis, A., E. Rudel, M. Zygmuntowski, and E. Koch, 2010: Bioclimatic maps for tourism purposes. *Physics and Chemistry of the Earth*, **35(1-2)**, 57-62.
Maynard, T. and N. Ranger, 2012: What Role for "Long-term Insurance" in Adaptation? An Analysis of the Prospects for and Pricing of Multi-year Insurance Contracts. *The Geneva Papers*, **37(2)**, 318-339.
Mcboyle, G., D. Scott, and B. Jones, 2007: Climate change and the future of snowmobiling in non-mountainous regions of Canada. *Managing Leisure*, **12(4)**, 237-250.
McColl, L., 2012: Assessing the Potential Impact of Climate Change on the UK's Electricity Network. *Met Office*, .
McGoodwin, J.R., 2007: Effects of climatic variability on three fishing economies in high-latitude regions: Implications for fisheries policies. *Marine Policy*, **31(1)**, 40-55.
MCII, 2008: International insurance mechanism - a proposal for the Copenhagen Agreed Outcome.Proceedings of Submission by the Munich Climate Insurance Initiative (MCII) to the UNFCCC: Proposal to the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA). December 1-10, 2008, Poznan, pp. 1-33.
MCII, 2012: Insurance solutions in the context of climate change-related loss and damage: Needs, gaps, and roles of the Convention in addressing loss and damage.Proceedings of Submitted to the SBI Work Program on Loss and Damage, .
McIlgorm, A., 2010: Economic impacts of climate change on sustainable tuna and billfish management: Insights from the Western Pacific. *Progress in Oceanography*, **86(1-2)**, 187-191.
Mendelsohn, R., K. Emanuel, S. Chonabayashi, and L. Bakkensen, 2012: The impact of climate change on global tropical cyclone damage. *Nature Climate Change*, **2**, 205-209 (DOI: 10.1038/NCLIMATE1357).
Mendoza, R.U., 2009: A Proposal for an Asian Rice Insurance Mechanism. *Global Economy Journal*, **9(1)**.
Merino, G., M. Barange, and C. Mullon, 2010: Climate variability and change scenarios for a marine commodity: Modelling small pelagic fish, fisheries and fishmeal in a globalized market. *Journal of Marine Systems*, **81(1-2)**, 196-205.
Meze-Hausken, E., A. Patt, and S. Fritz, 2009: Reducing climate risk for micro-insurance providers in Africa: a case study of Ethiopia. *Global Environmental Change*, **19**, 66-73.
Michel-Kerjan, E. and F. Morlaye, 2008: Extreme events, global warming, and insurance-linked securities: how to trigger the tipping point. *The Geneva Papers*, **33**, 153-176.
Michel-Kerjan, E. and H. Kunreuther, 2011: Redesigning flood insurance. *Science*, **333**, 408-409.
Michel-Kerjan, E.O., 2010: Catastrophe economics: the national flood insurance program. *Journal of Economic Perspectives*, **24(4)**, 165-186.

Middelkoop, H., K. Daamen, D. Gellens, W. Grabs, J.C.J. Kwadijk, H. Lang, B.W.A.H. Parmet, B. Schadler, J. Schulla, and K. Wilke, 2001a: Impact of Climate Change on Hydrological Regimes and Water Resources Management in the Rhine Basin. *Climatic Change*, , 105-128.
Middelkoop, H., K. Daamen, D. Gellens, W. Grabs, J.C.J. Kwadijk, H. Lang, B.W.A.H. Parmet, B. Schädler, J. Schulla, and K. Wilke, 2001b: Impact of climate change on hydrological regimes and water resources management in the Rhine basin. *Climatic Change*, **49(1-2)**, 105-128.
Mideksa, T.K. and S. Kallbekken, 2010: The Impact of Climate Change on the Electricity Market: A Review. *Energy Policy*, **38(7)**, 3579–3585.
Millerd, F., 2010: The Potential Impacts of Climate Change on Great Lakes International Shipping. *Climatic Change*, .
Mills, B.N. and J. Andrey, 2002: *Climate change and transportation: Potential interactions and impacts.* In: The Potential Impacts of Climate Change on Transportation - Federal Research Partnership Workshop. DOT Center for Climate Change and Environmental Forecasting.
Mills, E., 2009: A global review of insurance industry responses to climate change. *The Geneva Papers*, **34**, 323-359.
Mills, E., 2012: The Greening of Insurance. *Science*, **338**, 1424-1425.
Moen, J. and P. Fredman, 2007: Effects of climate change on alpine skiing in Sweden. *Journal of Sustainable Tourism*, **15(4)**, 418-437.
Mogaka, H., S. Gichere, and R. Davis, 2006: *Climate Variability and Water Resources Degradation in Kenya.* World Bank, Working Paper, Washington DC, pp. 105.
Moiseyev, A., B. Solberg, A.M.I. Kallio, and M. Lindner, 2011: An economic analysis of the potential contribution of forest biomass to the EU RES target and its implications for the EU forest industries. *Journal of Forest Economics*, **17(2)**, 197-213.
Monti, A., 2012: Public-private initiatives to cover extreme events. In: *The Geneva Reports - Risk and Insurance Research No.5. Extreme events and insurance: 2011 annus horribilis.* [Courbage, C. and W.R. Stahel(eds.)]. The Geneva Association (The International Association for the Study of Insurance Economics), Geneva, pp. 27-38.
Moreno, A., B. Amelung, and L. Santamarta, 2008: Linking beach recreation to weather conditions: A case study in Zandvoort, Netherlands. *Tourism in Marine Environments*, **5(2-3)**, 111-119.
Moreno, A. and B. Amelung, 2009: Climate change and tourist comfort on Europe's beaches in summer: A reassessment. *Coastal Management*, **37(6)**, 550-568.
Moreno, A., 2010: Mediterranean tourism and climate (change): A survey-based study. *Tourism and Hospitality, Planning and Development*, **7(3)**, 253-265.
Morrison, C. and C. Pickering, 2012: Limits to Climate Change Adaptation: Case Study of the Australian Alps. *Geographical Research*, .
Muir-Wood, R. and P. Grossi, 2008: The catastrophe modeling response to Hurricane Katrina. In: *Climate extremes and society.* [Diaz, H.F. and R.J. Murnane(eds.)]. Cambridge University Press, Cambridge, pp. 296-319.
Mukheibir, P., 2013: *Potential Consequences of Projected Climate Change Impacts on Hydroelectricity Generation*.
Muller, M., 2007: Adapting to climate change: Water management for urban resilience. *Environment and Urbanization*, **19(1)**, 99-113.
Munich Re, 2005: *Weather catastrophes and climate change* Münchener Rückversicherungs-Gesellschaft, München, Germany, .
Munich Re., 2011: *Natural catastrophes 2010: analyses, assessments, positions.* In: Topics Geo. Muenchener Rückversicherungs-Gesellschaft, Muenchen, pp. 40pp.
Munich Re., 2012: *Natural catastrophes 2011: analyses, assessments, positions.* In: Topics Geo. Muenchener Rückversicherungs-Gesellschaft, Muenchen, pp. 56pp.
Narita, D., R.S.J. Tol, and D. Anthoff, 2009: Damage costs of climate change through intensification of tropical cyclone activities: An application of fund. *Climate Research*, **39(2)**, 87-97.
Narita, D., R.S.J. Tol, and D. Anthoff, 2010: Economic costs of extratropical storms under climate change: An application of FUND. *Journal of Environmental Planning and Management*, **53(3)**, 371-384.
Narita, D., K. Rehdanz, and R.S.J. Tol, 2012: Economic costs of ocean acidification: A look into the impacts on global shellfish production. *Climatic Change*, **113(3-4)**, 1049-1063.
Nassopoulos, H., P. Dumas, and S. Hallegatte, 2012: Adaptation to an uncertain climate change: Cost benefit analysis and robust decision making for dam dimensioning. *Climatic Change*, **114(3-4)**, 497-508.

Nee Schulz, S., 2012: Impacts of and Adaptation Options to Extreme Weather Events and Climate Change Concerning Thermal Power Plants. *Forthcoming*, .
Nelson, G., M. Rosegrant, J. Koo, R. Robertson, T. Sulser, R. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R. Valmonte-Santos, M. Ewing, and D. Lee, 2009: *Climate Change Impact on Agriculture and Costs of Adaptation.* In: Food Policy Report. International Food Policy Research Institute, Washington DC, pp. 30.
NETL (National Energy Technology Laboratory), 2007: *Potential Impacts of Climate Change on the Energy Sector.* NETL, Pittsburgh, PA, USA.
Neumann J, Price J, Chinowsky P, Wright L, Ludwig L, Streeter R, Jones R, Smith J, Perkins B, Jantarasami L, Martinich J (2013) Climate change risks to United States infrastructure: impacts on coastal development, roads, bridges, and urban drainage. Climatic Change (submitted).
Niesing, B., 2004: WIND provides storm warnings. *Fraunhofer Magazine*, **1**, 20-21.
Norton, B., 2006: Anatomy of a solar collector:: Developments in Materials, Components and Efficiency Improvements in Solar Thermal Collector Systems. *Refocus*, **7(3)**, 32-35.
Noy, I., 2009: The macroeconomic consequences of disasters. *Journal of Development Economics*, **88(2)**, 221-231.
Ntelekos, A.A., M. Oppenheimer, J.A. Smith, and A.J. Miller, 2010: Urbanization, climate change and flood policy in the United States. *Climatic Change*, **103(3)**, 597-616.
Nyaupane, G.P. and N. Chhetri, 2009: Vulnerability to climate change of nature-based tourism in the Nepalese Himalayas. *Tourism Geographies*, **11(1)**, 95-119.
Ott, H.E. and C. Richter, 2008: Anpassung an den Klimawandel–Risiken und Chancen für deutsche Unternehmen. *Wuppertal Papers*, **171**.
Pang, S.F.H., B. McKercher, and B. Prideaux, 2013: Climate Change and Tourism: An Overview. *Asia Pacific Journal of Tourism Research*, **18(1-2)**, 4-20.
Parkpoom, S., G.P. Harrison, and J.W. Bialek, 2005: Climate and weather uncertainty in the electricity industry. *International Energy Journal*, **6(1)**, 455-464.
Patt, A., P. Suarez, and U. Hess, 2010: How do small-holder farmers understand insurance, and how much do they want it? Evidence from Africa. *Global Environmental Change*, **20**, 153-161.
Patt, A., Pfenninger S., and J. Lilliestam, 2013: Vulnerability of solar energy infrastructure and output to climate change. *Forthcoming*, .
Patton, L., 2011: Why Insurers should focus on climate risk issues? *Risk Management, SC5*, .
Paudel, Y., 2012: A Comparative Study of Public—Private Catastrophe Insurance Systems: Lessons from Current Practices. *The Geneva Papers*, **37(2)**, 257-285 (Doi: 10.1057/gpp.2012.16).
Pearce, T.D., J.D. Ford, J. Prno, F. Duerden, J. Pittman, M. Beaumier, L. Berrang-Ford, and B. Smit, 2011: Climate change and mining in Canada. *Mitigation and Adaptation Strategies for Global Change*, **16(3)**, 347-368.
Peduzzi, P., B. Chatenoux, H. Dao, A. De Bono, C. Herold, J. Kossin, F. Mouton, and O. Nordbeck, 2012: Global trends in tropical cyclone risk. *Nature Climate Change*, **2**, 289-294 (Doi: 10.1038/NCLIMATE1410).
Pejovic, T., V. Williams, R. Noland, and R. Toumi, 2009: Factors Affecting the Frequency and Severity of Airport Weather Delays and the Implications of Climate Change for Future Delays. *Journal of the Transportation Research Board*, **No. 2139**, 97-106.
Perch-Nielsen, S.L., B. Amelung, and R. Knutti, 2009: Future climate resources for tourism in Europe based on the daily Tourism Climatic Index. *Climatic Change*, , 1-19.
Perch-Nielsen, S.L., 2010: The vulnerability of beach tourism to climate change-an index approach. *Climatic Change*, **100(3)**, 579-606.
Perez-Garcia, J., L.A. Joyce, A.D. Mcguire, and X. Xiao, 2002: Impacts of climate change on the global forest sector. *Climatic Change*, **54(4)**, 439-461.
Perry, A.H., 2006: Will predicted climate change compromise the sustainability of Mediterranean tourism? *Journal of Sustainable Tourism*, **14(4)**, 367-375.
Phelan, L., R. Taplin, A. Henderson-Sellers, and G. Albrecht, 2011: Ecological viability or liability? Insurance system responses to climate risk. *Environmental Policy and Governance*, **21**, 112-130.
Pickering, C.M. and R.C. Buckley, 2010: Climate Response by the Ski Industry: The Shortcomings of Snowmaking for Australian Resorts. *Ambio*, , 1-9.
Pickering, C.M., J.G. Castley, and M. Burtt, 2010: Skiing less often in a warmer world: Attitudes of tourists to climate change in an Australian ski resort. *Geographical Research*, **48(2)**, 137-147.

Pielke, J.A.J., 2007: Future economic damage from tropical cyclones: sensitivities to societal and climate changes. *Philosophical Transactions of the Royal Society,* **365**, 2717-2729.
Pielke, R.A.J. and M.W. Downton, 2000: Precipitation and damaging floods: Trends in the United States, 1932-97. *Journal of Climate,* **13(20)**, 3625-3637.
Pinto, J.G., E.L. Fröhlich, G.C. Leckebusch, and U. Ulbrich, 2007: Changing European storm loss potentials under modified climate conditions according to ensemble simulations of the ECHAM5/MPI-OM1 GCM. *Natural Hazards and Earth System Sciences,* **7**, 165-175.
Pinto, J.G., C.P. Neuhaus, G.C. Leckebusch, M. Reyers, and M. Kerschgens, 2009: Estimation of wind storm impacts over Western Germany under future climate conditions using a statistical-dynamical downscaling approach. *Tellus A*, **62**, 188-201.
Pinto, J.G., M.K. Karremann, K. Born, P.M. Della-Marta, and M. Klawa, 2012: Loss potentials associated with European windstorms under future climate conditions. *Climate Research,* **54(1)**, 1-20 (Doi: 10.3354/cr01111).
Pons-Pons, M., P.A. Johnson, M. Rosas-Casals, B. Sureda, and E. Jover, 2012: Modeling climate change effects on winter ski tourism in Andorra. *Climate Research,* **54(3)**, 197-207.
Potocka, I. and A. Zajadacz, 2009: Weather and climate as elements of tourism space controlling the demand for and forms of tourist activity. *Quaestiones Geographicae,* **(28 A1)**, 53-64.
Potter, J., V. Burkett, M. Savonis, and D. Dokken, 2008: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.* [Potter, J., Burkett, V., Savonis, M. and Dokken, D. (eds.)]. U.S. Climate Change Science Program.
Pouta, E., M. Neuvonen, and T. Sievänen, 2009: Participation in cross-country skiing in Finland under climate change: Application of multiple hierarchy stratification perspective. *Journal of Leisure Research,* **41(1)**, 91-108.
Prideaux, B. and K.E. Mcnamara, 2012: Turning a Global Crisis into a Tourism Opportunity: The Perspective from Tuvalu. *International Journal of Tourism Research,* .
Pryor, S.C., J.T. Schoof, and R.J. Barthelmie, 2006: Winds of change?: Projections of near-surface winds under climate change scenarios. *Geophys. Res. Lett.,* **33(11)**, L11702.
Pryor, S.C. and R.J. Barthelmie, 2010: Climate change impacts on wind energy: A review. *Renewable and Sustainable Energy Reviews*, **14(1)**, 430-437.
Pryor, S.C. and R.J. Barthelmie, 2013: Assesing the Vulnerability of Wind Energy to Climate Change and Extreme Events. *Forthcoming,* .
Pryor, S.C., R.J. Barthelmie, N.E. Clausen, M. Drews, N. MacKellar, and E. Kjellström, 2011(a): Analyses of possible changes in intense and extreme wind speeds over northern Europe under climate change scenarios. *Climate Dynamics,* **38**, 189-208.
Pryor, S.C. and R.J. Barthelmie, 2011(b): Assessing climate change impacts on the near-term stability of the wind energy resource over the USA. *Proceedings of the National Academy of Sciences,* **108**, 8167-8171.
Pryor, S.C. and Schoof, 2010: Importance of the SRES in projections of climate change impacts on near-surface wind regimes. *Meteorologische Zeitschrift,* **19**, 267-274.
Qureshi, Z. and D. Reinhard, 2011: Making insurance work for the poor.[Munich Re Foundation (ed.)]. Proceedings of the 6th International Microinsurance Conference 2010. November 9-11, 2010, Manila, Philippines., pp. 1-89.
Raible, C.C., S. Kleppek, M. Wüest, D.N. Bresch, A. Kitoh, H. Murakami, and T.F. Stocker, 2012: Atlantic hurricanes and associated insurance loss potentials in future climate scenarios: limitations of high-resolution AGCM simulations. *Tellus A,* **64(15672)** (Doi: 10.3402/tellusa.v64i0.15672).
Ramakrishnan, S.K., 2011: Adaptation cost of diarrhea and malaria in 2030 for India. *Indian Journal of Occupational and Environmental Medicine,* **15(2)**, 64-67.
Ranger, N. and F. Niehoerster, 2012: Deep uncertainty in long-term hurricane risk: scenario generation and implications for future climate experiments. *Global Environmental Change,* .
Raymond, C.M. and G. Brown, 2011: Assessing spatial associations between perceptions of landscape value and climate change risk for use in climate change planning. *Climatic Change,* **104(3-4)**, 653-678.
Reed, D.A., 2008: Electric utility distribution analysis for extreme winds. *Journal of Wind Engineering and Industrial Aerodynamics,* **96(1)**, 123-140.
Reilly, J.M., N. Hohmann, and S. Kane, 1994: Climate Change and Agricultural Trade: Who Benefits, Who Loses? *Global Environmental Change,* **4(1)**, 24-36.
Reilly, J.M., S. Paltsev, B. Felzer, X. Wang, D.W. Kicklighter, J.M. Melillo, R.G. Prinn, M. Sarofim, A.P. Sokolov, and C. Wang, 2007: Global Economic Effects of Changes in Crops, Pasture, and Forests due to Changing Climate, Carbon Dioxide, and Ozone. *Energy Policy,* **35**, 5370-5383.

Reinhold, T., B. O'Connor, and C. Iskowitz, 2012: Reducing vulnerabilities through science. . In: *Severe weather in North America. Perils, Risks, Insurance.* [Kron, W. and F. Wöst(eds.)]. Munich Re, Munich, pp. 197-225.
Ren Guoyu, 1996: Global climate changes and the tourism of China. *Journal of Chinese Geography,* **6(2)**, 97-102.
Richardson, R.B. and J.B. Loomis, 2005: Climate change and recreation benefits in an alpine national park. *Journal of Leisure Research,* **37(3)**, 307-320.
Richter, C., S. Teske, and R. Short, 2009: Concentrating solar power. Global outlook 2009. *Greenpeace, ESTELA and SolarPACES,* .
Ronneberger, K., M. Berrittella, F. Bosello, and R.S.J. Tol, 2009: KLUM@GTAP: Introducing biophysical aspects of land-use decisions into a computable general equilibrium model a coupling experiment. *Environmental Modeling and Assessment,* **14(2)**, 149-168.
Rossello, J., 2011: North Atlantic Oscillation influences on European airline traffic. *Transportation Research Part D: Transport and Environment,* **16(2)**, 183-187.
Rosselló-Nadal, J., A. Riera-Font, and V. Cárdenas, 2010: The impact of weather variability on British outbound flows. *Climatic Change,* , 1-12.
Rübbelke, D.T.G. and S. Vögele, 2010: Impacts of Climate Change on European Critical Infrastructures: The Case of the Power Sector. *Basque Centre for Climate Change Working Paper,* **2010-08**.
Rutty, M. and D. Scott, 2010: Will the Mediterranean become "Too Hot" for tourism? A reassessment. *Tourism and Hospitality, Planning and Development,* **7(3)**, 267-281.
Saarinen, J. and K. Tervo, 2006: Perceptions and adaptation strategies of the tourism industry to climate change: The case of Finnish nature-based tourism entrepreneurs. *International Journal of Innovation and Sustainable Development,* **1(3)**, 214-228.
Saarinen, J., W.L. Hambira, J. Atlhopheng, and H. Manwa, 2012: Tourism industry reaction to climate change in Kgalagadi South District, Botswana. *Development Southern Africa,* **29(2)**, 273-285.
Sabbioni, C., M. Cassar, P. Brimblecombe, and R.-. Lefevre, 2009: Vulnerability of cultural heritage to climate change. *Pollution Atmospherique,* **(202)**, 157-169.
Sailor, D.J., M. Smith, and M. Hart, 2008: Climate change implications for wind power resources in the Northwest United States. *Renewable Energy,* **33(11)**, 2393-2406.
Sander, J., J.F. Eichner, E. Faust, and M. Steuer, planned 2013: Rising variability in thunderstorm-related U.S. losses as a reflection of changes in large-scale thunderstorm forcing. *Submitted Paper,* .
Schaefli, B., D. Balin Talamba, and A. Musy, 2007: Quantifying hydrological modeling errors through a mixture of normal distributions. *Journal of Hydrology,* **332**, 303-315.
Schmidt, P., R. Steiger, and A. Matzarakis, 2012: Artificial snowmaking possibilities and climate change based on regional climate modeling in the Southern Black Forest. *Meteorologische Zeitschrift,* **21(2)**, 167-172.
Schreider, S.Y., D.I. Smith, and A.J. Jakeman, 2000: Climate change impacts on urban flooding. *Climatic Change,* **47(1-2)**, 91-115.
Schwarze, R., H. Schwindt, H. Weck-Hannemann, P. Raschky, F. Zahn, and G.G. Wagner, 2011: Natural hazard insurance in Europe: tailored responses to climate change are needed. *Environmental Policy and Governance,* **21**, 14-30.
Schwarze, R. and G.G. Wagner, 2007: The political economy of natural disaster insurance: Lessons from the failure of a proposed compulsory insurance scheme in Germany. *European Environment,* **17(6)**, 403-415.
Schwarze, R., M. Schwindt, H. Weck-Hannemann, P. Raschky, F. Zahn, and G.G. Wagner, 2011: Natural hazard insurance in Europe: Tailored responses to climate change are needed. *Environmental Policy and Governance,* **21(1)**, 14-30.
Schwierz, C., P. Köllner-Heck, E. Zenklusen-Mutter, D.N. Bresch, P.-. Vidale, M. Wild, and C. Schär, 2010: Modelling European winter wind storm losses in current and future climate. *Climatic Change,* **101**, 485-514.
Scott, M., S. Gupta, E. E. Jáuregui, J. Nwafor, D. Satterthwaite, W. Wanasinghe T., and M. Yoshino, 2001: Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. **WG II**, 381-416.
Scott, D., G. McBoyle, and B. Mills, 2003: Climate change and the skiing industry in southern Ontario (Canada): Exploring the importance of snowmaking as a technical adaptation. *Climate Research,* **23(2)**, 171-181.
Scott, D., G. McBoyle, and M. Schwartzentruber, 2004: Climate change and the distribution of climatic resources for tourism in North America. *Climate Research,* **27(2)**, 105-117.
Scott, D. and B. Jones, 2006: The impact of climate change on golf participation in the Greater Toronto Area (GTA): A case study. *Journal of Leisure Research,* **38(3)**, 363-380.

Scott, D., G. McBoyle, A. Minogue, and B. Mills, 2006: Climate change and the sustainability of ski-based tourism in eastern North America: A reassessment. *Journal of Sustainable Tourism*, **14(4)**, 376-398.
Scott, D. and B. Jones, 2007: A regional comparison of the implications of climate change for the golf industry in Canada. *Canadian Geographer,* **51(2)**, 219-232.
Scott, D., B. Jones, and J. Konopek, 2007: Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park. *Tourism Management*, **28(2)**, 570-579.
Scott, D. and G. McBoyle, 2007: Climate change adaptation in the ski industry. *Mitigation and Adaptation Strategies for Global Change*, **12(8)**, 1411-1431.
Scott, D., G. McBoyle, and A. Minogue, 2007: Climate change and Quebec's ski industry. *Global Environmental Change*, **17(2)**, 181-190.
Scott, D., J. Dawson, and B. Jones, 2008a: Climate change vulnerability of the US Northeast winter recreation-tourism sector. *Mitigation and Adaptation Strategies for Global Change,* **13(5-6)**, 577-596.
Scott, D., S. Gössling, and C.R. De Freitas, 2008b: Preferred climates for tourism: case studies from Canada, New Zealand and Sweden. *Climate Research,* **38(1)**, 61-73.
Scott, D., S. Gössling, and C.M. Hall, 2012a: International tourism and climate change. *Wiley Interdisciplinary Reviews: Climate Change,* **3(3)**, 213-232.
Scott, D., M.C. Simpson, and R. Sim, 2012b: The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise. *Journal of Sustainable Tourism,* **20(6)**, 883-898.
Seo, J. and O. Mahul, 2009: The World Bank Policy Research Working Paper 4959. In: *The impact of climate change on catastrophe risk model. Implications for catastrophe risk markets in developing countries.* The World Bank, Washington D.C., pp. 16pp.
Serquet, G. and M. Rebetez, 2011: Relationship between tourism demand in the Swiss Alps and hot summer air temperatures associated with climate change. *Climatic Change,* , 1-10.
Shaw, W.D. and J.B. Loomis, 2008: Frameworks for analyzing the economic effects of climate change on outdoor recreation. *Climate Research,* **36(3)**, 259-269.
Sherement, O. and A. Lucas, 2009: Global loss diversification in the insurance sector. *Insurance: Mathematics and Economics,* **44(3)**, 415-425 (Doi: 10.1016/j.insmatheco.2008.12.001).
Shih, C., S. Nicholls, and D.F. Holecek, 2009: Impact of weather on downhill ski lift ticket sales. *Journal of Travel Research,* **47(3)**, 359-372.
Smith, A.B. and R.W. Katz, 2013: US billion-dollar weather and climate disasters: data sources, trends, accuracy and biases. *Natural Hazards,* (Doi: 10.1007/s11069-013-0566-5).
Smith, K., 1990: Tourism and climate change. *Land use Policy,* **7(2)**, 176-180.
Sohngen, B. and R. Mendelsohn, 1997: A dynamic model of forest carbon storage in the United States during climatic change. *Critical Reviews in Environmental Science and Technology,* **27(SPEC. ISS.)**, S309-S321.
Sohngen, B. and R. Mendelsohn, 1998: Valuing the Impact of Large-Scale Ecological Change in a Market: The Effect of Climate Change on U.S. Timber. *American Economic Review,* **88(4)**, 686-710.
Sohngen, B., R. Mendelsohn, and R. Sedjo, 2001: A Global Model of Climate Change Impacts on Timber Markets. *Journal of Agricultural and Resource Economics,* **26(2)**, 326-343.
SPF, 2009: Impact Resistance Solarthermische Kollektoren - Einteilung in HW Klassen. *Test Report; Institut Für Solartechnik, Rapperswil, Switzerland.*, .
Steger, C., S. Kotlarski, T. Jonas, and C. Schär, 2012: Alpine snow cover in a changing climate: a regional climate model perspective. *Climate Dynamics,* , 1-20.
Steiger, R. and M. Mayer, 2008: Snowmaking and climate change: Future options for snow production in tyrolean ski resorts. *Mountain Research and Development,* **28(3-4)**, 292-298.
Steiger, R., 2010: The impact of climate change on ski season length and snowmaking requirements in Tyrol, Austria. *Climate Research,* **43(3)**, 251-262.
Steiger, R., 2012: Scenarios for skiing tourism in Austria: Integrating demographics with an analysis of climate change. *Journal of Sustainable Tourism,* **20(6)**, 867-882.
Stewart, W. and D. Willard, 2010: Kivalina v. ExxonMobil dissmissed by Federal Trial Court. In: *Liability for climate change? Experts' views on a potential emerging risk.* [Munich Re (ed.)]. Munich Re, Muenchen, pp. 11-13.
Strulik, H., 2008: Geography, health, and the pace of demo-economic development. *Journal of Development Economics,* **86(1)**, 61-75.

Strzepek, K, B Boehlert, A. McCluskey, W. Farmer, J. Neumann , M. Fuchs, 2011, Assessment of the Impacts of Climate Change on Multi-Sector Investment Opportunities in the Zambezi River Basin, IEc Report to World Bank

Strzepek K, Smith J, Martinich J, Neumann J, Boehlert B, Hejazi M, Henderson J, Wobus C, Calvin K, Johnson D, R Jones, Monier E, Strzepek J, Yoon JH (2013) Climate change impacts on water resources in the United States. Climatic Change (submitted).

Subak, S., J.P. Palutikof, M.D. Agnew, S.J. Watson, C.G. Bentham, M.G.R. Cannell, M. Hulme, S. McNally, J.E. Thornes, D. Waughray, and J.C. Woods, 2000: The impact of the anomalous weather of 1995 on the U.K. economy. *Climatic Change,* **44(1-2)**, 1-26.

Supreme Court of Virginia, U.S.A., 2012: Declaratory judgment following rehearing. In: *The AES Corporation v. Steadfast Insurance Company. Record No.100764. Opinion of 20 April 2012.*[Goodwyn, S.B. (ed.)]. Supreme Court of Virginia, U.S.A., www.courts.state.va.us/opinions/opnscwp/1100764r.pdf

Swiss Confederation, 2008: Funding scheme for Bali Action Plan: A Swiss proposal for global solidarity in financing adaptation ("Bali Paper" updated).Proceedings of Bonn Climate Change Conference (SB28), June 4-13, 2008, Bonn, pp. 1-59.

Swiss Re, 2012: *No.2/2012. Natural catastrophes and man-made disasters in 2011: historic losses surface from record earthquakes and floods.* In: Sigma. Swiss Reinsurance Company Ltd., Zürich, pp. 40pp.

Swiss Re, 2013a: *No1/2013. Partnering for food security in emerging markets.* In: Sigma. Swiss Reinsurance Company Ltd., Zürich.

Swiss Re, 2013b: *World insurance in 2011 – Non-life ready for take-off.* In: Sigma. Swiss Reinsurance Company Ltd., Zürich.

Tang, K.K., D. Petrie, and D.S.P. Rao, 2009: The income-climate trap of health development: A comparative analysis of African and Non-African countries. *Social Science and Medicine,* **69(7)**, 1099-1106.

Taylor, R.J. and H.M. Tollin, 2009: Insurance Market for Global Warming Heats Up: Old Products and New Policies Respond to Climate Change Risks. *Environmental Claims Journal,* **21(3)**, 247-261 (Doi:10.1080/10406020903109822).

Taylor, T. and R.A. Ortiz, 2009: Impacts of climate change on domestic tourism in the UK: A panel data estimation. *Tourism Economics,* **15(4)**, 803-812.

Tervo, K., 2008: The operational and regional vulnerability of winter tourism to climate variability and change: The case of the finnish nature-based tourism entrepreneurs. *Scandinavian Journal of Hospitality and Tourism,* **8(4)**, 317-332.

Thieken, A.H., T. Petrow, H. Kreiblich, and B. Merz, 2006: Insurability and mitigation of flood losses in private households in Germany. *Risk Analysis*, **26**, 383-395.

Toth, F.L., 2013: The impacts of climate change on energy demand. *Forthcoming,* .

Towler, E., Raucher, B., Rajagopalan, B., Rodriguez, A., Yates, D., & Summers, R. S. (2011). Incorporating Climate Uncertainty in a Cost Assessment for a New Municipal Source Water. *Journal of Water Resources Planning and Management*.

Trærup, S.L.M., R.A. Ortiz, and A. Markandya, 2011: The costs of climate change: A study of cholera in Tanzania. *International Journal of Environmental Research and Public Health,* **8(12)**, 4386-4405.

Travers, J. and V.G. Payne, 1998: The impact of climate change on traditional seasonal ranges for high street women's wear in England. *Journal of Fashion Marketing and Management*, **2(4)**, 370-382.

TRB, 2008a: *Potential Impacts of Climate Change on U.S. Transportation: Transportation Research Board Special Report 290.* Transportation Research Board, National Research Council; National Academies.

TRB, 2008b: *Potential Impacts of Climate Change on U.S. Transportation.* In: TRB Special Report 290. Transportation Research Board, Washington DC.

Troccoli, A. (ed.), 2010: *Management of Weather and Climate Risk in the Energy Industry.* Springer, Dordrecht, The Netherlands, .

Tsai, H.-., C.-. Tseng, S.-. Tzeng, T.-. Wu, and J.-. Day, 2012: The impacts of natural hazards on Taiwan's tourism industry. *Natural Hazards,* **62(1)**, 83-91.

Turton, S., T. Dickson, W. Hadwen, B. Jorgensen, T. Pham, D. Simmons, P. Tremblay, and R. Wilson, 2010: Developing an approach for tourism climate change assessment: Evidence from four contrasting Australian case studies. *Journal of Sustainable Tourism*, **18(3)**, 429-447.

UNCTAD, 2009: *Maritime Transport and the Climate Change Challenge, Summary of Proceedings.* United Nations Conference on Trade and Development.

UNECE and UNCTAD, 2010: Note by the United Nations Economic Commission for Europe and United Nations Conference on Trade and Development Secretariats.Proceedings of Joint Workshop on Climate Change Impacts on International Transport Networks, 7-8 September 2010, .
UNFCCC, 2007. Investment and financial flows to address climate change. Background paper on analysis of existing and planned investment and financial flows relevant to the development of effective and appropriate international response to climate change. UNFCCC, Bonn, Germany, 272pp.
URS, 2010: *Adapting Energy, Transport, and Water Infrastructure to the Long-Term Impacts of Climate Change, Summary Report.* URS Corporation Limited.
USGCRP, 2009: *Global Climate Change Impacts in the United States.* Cambridge University Press, New York, N.Y., USA.
Uyarra, M.C., I.M. Côté, J.A. Gill, R.R.T. Tinch, D. Viner, and A.R. Watkinson, 2005: Island-specific preferences of tourists for environmental features: Implications of climate change for tourism-dependent states. *Environmental Conservation*, **32(1)**, 11-19.
Van den Berg, R. and M. Faure, 2006: Compulsory insurance of loss to property caused by natural disasters: competition or solidarity? *World Competition*, **29(1)**, 25-54.
van den Berg, M., 2010: Household income strategies and natural disasters: Dynamic livelihoods in rural Nicaragua. *Ecological Economics*, **69(3)**, 592-602.
Van der Vliert, E., 2008: *Climate, Affluence, and Culture* Cambridge University Press, Cambridge, pp. 264.
Van Nostrand, J.M. and J.G. Nevius, 2011: Parametric Insurance: Using Objective Measures to Address the Impacts of Natural Disasters and Climate Change. *Environmental Claims Journal*, **23(3-4)**, 227-237 (Doi:10.1080/10406026.2011.607066).
Van Vliet, M.T.H., J.R. Yearsley, F. Ludwig, S. Vögele, D.P. Lettenmaier, and P. Kabat, 2012: Vulnerability of US and European electricity supply to climate change. *Nature Climate Change*, **2(9)**, 676-681.
Vergara, W., A. Deeb, A. Valencia, R. Bradley, B. Francou, A. Zarzar, A. Grunwaldt, and S. Haeussling, 2007: Economic Impacts of Rapid Glacier Retreat in the Andes
. *Eos, Transactions American Geophysical Union*, **88(25)**, 261-268.
Vlasova, L.V. and G.S. Rakitina, 2010: Natural Risks Management in the Gas Transmission System (GTS) of Russia and the Contribution of Climate Services under Global Climate Change. In: *Management of Weather and Climate Risk in the Energy Industry*. [Troccoli, A. (ed.)]. Springer, Bilthoven, The Netherlands, pp. 315-325.
Wall, G., 1998: Implications of global climate change for tourism and recreation in wetland areas. *Climatic Change*, **40(2)**, 371-389.
Walter, A., K. Keuler, D. Jacob, R. Knoche, A. Block, S. Kotlarski, G. Muller-Westermeier, D. Rechid, and W. Ahrens, 2006: A high resolution reference data set of German wind velocity 19512001 and comparison with regional climate model results. *Meteorologische Zeitschrift*, **15**, 585-596.
Wang, S., Y. He, and X. Song, 2010: Impacts of climate warming on Alpine glacier tourism and adaptive measures: A case study of Baishui Glacier No. 1 in Yulong Snow Mountain, Southwestern China. *Journal of Earth Science*, **21(2)**, 166-178.
Ward, A.M., 2013: The Effect of Weather on Grid Systems and the Reliability of Electricty Supply. *Forthcoming*, .
Ward, R.E.T., C. Herweijer, N. Patmore, and R. Muir-Wood, 2008: The role of insurers in promoting adaptation to the impacts of climate change. *The Geneva Papers*, **33**, 133-139.
Ward, P.J., K.M. Strzepek, W.P. Pauw, L.M. Brander, G.A. Hughes, and J.C.J.H. Aerts, 2010: Partial costs of global climate change adaptation for the supply of raw industrial and municipal water: A methodology and application. *Environmental Research Letters*, **5(4)**.
Warner, K. and A. Spiegel, 2009: Climate change and emerging markets: the role of the insurance industry in climate change management. In: *The Geneva Reports - Risk and Insurance Research No. 2. The insurance industry and climate change - contribution to the global debate.* [The Geneva Association (ed.)]. The Geneva Association (The International Association for the Study of Insurance Economics), Geneva, pp. 83-95.
Watson, C.C., Jr. and M.E. Johnson, 2008: Integrating hurricane loss models with climate models. In: *Climate extremes and society.* [Diaz, H.F. and R.J. Murnane(eds.)]. Cambridge University Press, Cambridge, pp. 209-224.
Whitehead, J.C., B. Poulter, C.F. Dumas, and O. Bin, 2009: Measuring the economic effects of sea level rise on shore fishing. *Mitigation and Adaptation Strategies for Global Change*, **14(8)**, 777-792.

Wilbanks, T.J., P. Romero Lankao, M. Bao, F. Berkhout, S. Cairncross, J.-. Ceron, M. Kapshe, R. Muir-Wood, and R. and Zapata-Marti, 2007: Industry, settlement and society. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* , 357-390.
Williams, E., 2013: Economic Impacts of Climate Change and Extreme Weather Events on the Energy Sector: Current State of Research and Analysis. *Climatic Change,* **Forthcoming**.
Williams, E. and F.L. Toth, 2013: Nuclear Power: Impacts of Climate Change and Extreme Weather. Forthcoming.
Winkler, J., L. Dueñas-Osorio, R. Stein, and D. Subramanian, 2010: Performance assessment of topologically diverse power systems subjected to hurricane events. *Reliability Engineering and System Safety,* **95(4)**, 323-336.
Winters, P., R. Murgai, E. Sadoulet, A. De Janvry, and G. Frisvold, 1998: Economic and welfare impacts of climate change on developing countries. *Environmental and Resource Economics,* **12(1)**, 1-24.
Wirtz, A., P. Löw, T. Mahl, and S. Yildirim, planned 2013: Hitting the poor – public private partnerships as an option: impact of natural catastrophes in economies at various stages of development. In: *Extreme natural Hazards, Disaster Risks and Societal Implications.* [Ismail-Zadeh, A., J. Fucugauchi, A. Kijko, K. Takeuchi, and I. Zaliapin(eds.)]. Cambridge University Press, Cambridge, .
Wolfsegger, C., S. Gössling, and D. Scott, 2008: Climate Change Risk Appraisal in the Austrian Ski Industry. *Tourism Review International,* **12(1)**, 13-23.
World Bank, 2006: *Ethiopia: Managing Water Resources to Maximize Sustainable Growth.* In: Country Water Resources Assistance Strategy. World Bank, Washington D.C., pp. 91.
Wright, L., P. Chinowsky, K. Strzepek, R. Jones, R. Streeter, J.B. Smith, J.-. Mayotte, A. Powell, L. Jantarasami, and W. Perkins, 2012: Estimated effects of climate change on flood vulnerability of U.S. bridges. *Mitigation and Adaptation Strategies for Global Change,* **17(8)**, 939-955.
WTO and UNEP, 2008: *Climate Change and Tourism - Responding to Global Challenges.* World Tourism Organization, Madrid.
WTTC, 2011: *Travel & Tourism 2011.* World Travel and Tourism Council, London.
Yates, D.N. and K.M. Strzepek, 1998: An assessment of integrated climate change impacts on the agricultural economy of Egypt. *Climatic Change,* **38(3)**, 261-287.
Yazdi, S.K. and A. Fashandi, 2010: The economic effects of climate change on fisheries and aquaculture. *In: ICEEA 2010 - 2010 International Conference on Environmental Engineering and Applications, Proceedings* pp. 335-340.
Yu, G., Z. Schwartz, and J.E. Walsh, 2009a: A weather-resolving index for assessing the impact of climate change on tourism related climate resources. *Climatic Change,* **95(3-4)**, 551-573.
Yu, G., S. Zvi, and J.E. Walsh, 2009b: Effects of climate change on the seasonality of weather for tourism in Alaska. *Arctic,* **62(4)**, 443-457.
Zahran, S., S. Weiler, S.D. Brody, M.K. Lindell, and W.E. Highfield, 2009: Modeling national flood insurance policy holding at the county scale in Florida, 1999-2005. *Ecological Economics,* **68(10)**, 2627-2636.
Zaninović, K. and A. Matzarakis, 2009: The bioclimatological leaflet as a means conveying climatological information to tourists and the tourism industry. *International Journal of Biometeorology,* **53(4)**, 369-374.
Zhu, J., 2011: Evaluation of an Insurance Scheme Based on the Weather Index - A case study of Anhui Province. *The Chinese Economy,* **44(6)**, 56-72.
Zimmerman, F.J. and M.R. Carter, 2003: Asset smoothing, consumption smoothing and the reproduction of inequality under risk and subsistence constraints. *Journal of Development Economics,* **71(2)**, 233-260.

Table 10-1: Main projected impacts of CC and EWEs on energy supply.

Tech	Changes in climatic or related attributes	Possible impacts	Adaptation options
Thermal and nuclear power plants	Increasing air temperature	Reduces efficiency of thermal conversion by 0.1-0.2% in the USA; by 0.1-0.5% in Europe where the capacity loss is estimated in the range of 1-2%/1°C temperature increase, accounting for decreasing cooling efficiency and reduced operation level/shutdown	Siting at locations with cooler local climates where possible
	Changing (lower) precipitation and increasing air temperature increases temperature and reduces the availability of water for cooling	Less power generation; annual average load reduction by 0.1-5.6% depending on scenario	Use of non-traditional water sources (e.g., water from oil and gas fields, coal mines and treatment, treated sewage); Re-use of process water from flue gases (can cover 25-37% of the power plants cooling needs), coal drying, condensers (dryer coal has higher heating value, cooler water enters cooling tower),, flue-gas desulphurization; Using ice to cool air before entering the gas turbine increases efficiency and output, melted ice used in cooling tower; Condenser mounted at the outlet of cooling tower to reduce evaporation losses (by up to 20%). Alternative cooling technologies: dry cooling towers, regenerative cooling, heat pipe exchangers; Costs of retrofitting cooling options depend on depend on features of existing systems, distance to water, required additional equipment, estimated at US$250,000-500,000/MW
	Increasing frequency of extreme hot temperatures	Exacerbating impacts of warmer conditions: reduced thermal and cooling efficiency; limited cooling water discharge; overheating buildings; self-ignition of coal stockpiles	Cooling of buildings (air conditioning) and of coal stockpiles (water spraying)
	Drought: reduced water availability	Exacerbating impacts of warmer conditions, reduced operation and output, shutdown	Same as reduced water availability under gradual CC
Hydropower	Increase/decrease in average water availability	Increased/reduced power output	Schedule release to optimize income
	Changes in seasonal and inter-annual variation in inflows (water availability)	Shifts in seasonal and annual power output; floods and lost output in the case of higher peak flows	Soft: adjust water management Hard: build additional storage capacity, improve turbine runner capacity
	Extreme precipitation causing floods	Direct and indirect (by debris carried from flooded areas) damage to dams and turbines, lost output due to releasing water through by-pass channels	Soft: adjust water management Debris removal Hard: increase storage capacity
Solar energy	Increasing mean temperature	Improving performance of TH (especially in colder regions), reducing efficiency of PV and CSP with water cooling; PV efficiency drops by ~0.5%/1°C temperature increase for crystalline Si and thin-film modules as well, but performance varies across types of modules, with thin film modules performing better; Long-term exposure to heat causes faster aging	

	Changing cloudiness	Increasing unfavourable (reduced output), decreasing beneficial (increased output) for all types, but evacuated tube collectors for TH can use diffuse insolation. CSP more vulnerable (cannot use diffuse light)	Apply rougher surface for PV panels that use diffuse light better; optimize fixed mounting angle for using diffuse light, apply tracking system to adjust angle for diffuse light conditions; Install/increase storage capacity
	Hot spells	Material damage for PV, reduced output for PV and CSP; CSP efficiency decreases by 3-9% as ambient temperature increases from 30 to 50°C and drops by 6% (tower) to 18% (trough) during the hottest 1% of time	Cooling PV panels passively by natural ail flows or actively by forced air or liquid coolants
	Hail	Material damage to TH: evacuated tube collectors are more vulnerable than flat plate collectors; Fracturing as glass plate cover, damage to photoactive material	Flat plate collectors: using reinforced glass to withstand hailstones of 35mm (all of 15 tested) or even 45 mm (10 of 15 tested); only 1 in 26 evacuated tube collectors withstood 45mm hailstones Increase protection to current standards or beyond them
Wind power	Windiness: total wind resource (multi-year annual mean wind power densities); *likely* to remain within ±50% of current values in Europe and North America; within ±25% of 1979-2000 historical values in contiguous USA	Change in wind power potential	Site selection
	Wind speed extremes: gust, direction change, shear	Structural integrity from high structural loads; fatigue, damage to turbine components; reduced output	Turbine design, lidar-based protection

Sources: (Nee Schulz, 2012),(Parkpoom *et al.*, 2005), (ADAM-Project, 2009),(NETL (National Energy Technology Laboratory), 2007; Feeley III *et al.*, 2008; Ott and Richter, 2008; Förster and Lilliestam, 2009; Hoffmann *et al.*, 2010; Linnerud *et al.*, 2011; Mukheibir, 2013; Williams, 2013), (Schaefli *et al.*, 2007; Markoff and Cullen, 2008),(Droogers, 2009). (EPA , 2001; Norton, 2006; Pryor *et al.*, 2006; Walter *et al.*, 2006; Christensen and Busuioc, 2007; DOE, 2007; Bloom *et al.*, 2008; Haugen and Iversen, 2008; Leckebusch *et al.*, 2008; Sailor *et al.*, 2008; Honeyborne, 2009; Kurtz *et al.*, 2009; SPF, 2009; Pryor and Barthelmie, 2010; Pryor and Schoof, 2010; Pryor and Barthelmie, 2011(b); Kurtz *et al.*, 2011; Patt *et al.*, 2013; Pryor and Barthelmie, 2013).
Notes: TH: thermal heating; PV: photovoltaic; CSP: concentrating solar power.

Table 10-2: Main impacts of CC and EWEs on pipelines and the electricity grid.

Tech	Changes in climatic or related attribute	Impacts	Adaptation options
Pipelines	Melting permafrost	Destabilizing pillars, obstructing access for maintenance and repair	Adjust design code and planning criteria, install disaster mitigation plans
	Increasing high wind, storms, hurricanes	Damage to offshore and onshore pipelines and related equipment, spills; lift and blow heavy objects against pipelines, damage equipment	Enhance design criteria, update disaster preparedness
	Flooding caused by heavy rain, storm surge or sea-level rise	Damage to pipelines, spills	Siting (exclude flood plains), water proofing
Electricity grid	Increasing average temperature	Increased transmission line losses	Include increasing temperature in the design calculation for maximum temperature/rating
	Increasing high wind, storms, hurricanes	Direct mechanical damage to overhead lines, towers, poles, substations, flashover caused by live cables galloping and thus touching or getting too close to each other; indirect mechanical damage and short circuit by trees blown over or debris blown against overhead lines	Adjust wind loading standards, reroute lines alongside roads or across open fields, vegetation management, improved storm and hurricane forecasting
	Extreme high temperatures	Lines and transformers may overheat and trip off; flashover to trees underneath expanding cable	Increase system capacity, increase tension in the line to reduce sag, add external coolers to transformers
	Combination of low temperature, wind and rain, ice storm	Physical damage (including collapse) of overhead lines and towers caused by ice build-up on them	Enhance design standard to withstand larger ice and wind loading, reroute lines alongside roads or across open fields, improve forecasting of ice storms impacts on overhead lines and on transmission circuits

Sources: (Bayliss, 2007; Krausmann and Mushtaq, 2008; Reed, 2008; Hines *et al.*, 2009; Winkler *et al.*, 2010; Cruz and Krausmann, 2013),(Vlasova and Rakitina, 2010), (Ward, 2013), (McColl, 2012).

Table 10-3: Economy-wide implications of impacts of climate change and extreme weather on the energy sector.

Study	Model Type	Climate Impacts Modelled	Energy/Economic Impacts	Regions	Sectors Studied
(Bosello *et al.*, 2009)	IAM	Rising temperatures/ changing demand for energy; impacts from 4 other sectors/events (Global, 2001 - 2050)	Change in GDP in 2050 due to rising temperatures and changing energy demand: 0% to 0.75% (+1.2°C); -0.1% to 1.2% (+3.1°C)	14	4
(Jorgenson *et al.*, 2004)	CGE	Rising temperatures/ changing demand for energy; climate impacts from 3 other sectors (USA, 2000 - 2100)	Optimistic adaptation: 4% to 6.7% higher energy productivity per year (2000 – 2100); Output from electricity: -6% in 2050; GDP is +0.7% (aggregate all sectors, avg annual 2000 – 2100) Pessimistic adaptation: 0.5% to 2.2% lower energy productivity per year; Output from electricity: +2% in 2050; GDP is -0.6% (aggregate impact all sectors)	1	35
(Bosello *et al.*, 2007)	CGE	Rising temperatures/ changing demand for energy (Global, 2050)	Change in GDP in 2050 (perfect competition): -0.297% to 0.027%; Change in GDP in 2050 (imperfect competition): -0.303% to 0.027%	8	1
(Aaheim *et al.*, 2009)	CGE	Change in precipitation -> share of hydro power; rising temperatures/ changing demand for energy ; impacts from 4 other sectors (Western Europe, 2071 – 2100)	Impact from all sectors in 2100: GDP in cooler regions: -1% to -0.25% GDP in warmer regions: -3% to -0.5% Adaptation can mitigate 80% to 85% of economic impact	8	11
(Boyd and Ibarraran, 2009)	CGE	Drought scenario affecting hydro plus 3 other sectors (Mexico, 2005 - 2026)	Generation output in 2026: -2.1% Refining output: -10.1% Coal output: -7.8% NG output: -2% Crude oil output: +1.7% GDP: -3% With adaptation: Generation output in 2026: 0.24%% Refining output: 1.36%% Coal output: 1.09%% NG output: 0.34%% Crude oil output: 0.22% GDP: 0.33%	1	2
(Jochem *et al.*, 2009)	PE/ CGE	Rising temperatures/ changing demand for energy; Change in technical potential of renewables; Change in rainfall -> change in hydro; High temperatures -> water temperatures exceeding regulatory limits (Europe); High temperatures -> greater electric grid losses and lower thermal efficiency; generic extreme events -> reduced capital stock in CGE model (EU27+2, 2005 – 2050)	GDP (Europe): -50 billion € p.a. in 2035 GDP (Europe): -240 billion € p.a. in 2050 GDP (EU regions): -0.1% to -0.4% in 2035 GDP (EU regions): -0.6% to -1.3% in 2050 Jobs (Europe): -380K in 2035 Jobs (Europe): -1 million in 2050	25	1
(Eboli *et al.*, 2010b)	CGE	Rising temperatures/ changing demand for energy; climate impacts	By 2100, change in GDP due to climate impacts on energy	8	17

		in 4 other sectors modelled (Global, 2002 - 2100)	demand vary by country between ~ -0.15% and 0.7%. USA and Japan were negative and all other countries positive. Overall economic impact from all sectors is neutral to positive for developed countries and negative for developing.		
(Golombek *et al.*, 2011)	PE	Rising temperatures/ changing demand for energy; Rising temp/ reduced thermal efficiency; change in water inflow (Western Europe, 2030)	Net impact on the price of electricity is a 1% increase. Generation decreases by 4%	13	4
(Bye *et al.*, 2006)	PE	Water shortages (Nordic countries, hypothetical 2 year period)	Water shortage scenarios can lead to a 100% increase in electricity prices at peak demand over a 2 year period. Higher prices lead to marginal reductions in demand (~ 1% - 2.25%).	4	1
(Koch *et al.*, 2012)	PE	High temperatures -> water temperatures exceeding regulatory limits (Berlin, 2010 - 2050)	Thermal plant outages amounting to 60 million EURO for plants in Berlin through 2050	1	1
(Gabrielsen *et al.*, 2005)	Econo metric	Rising temperatures/ changing demand for energy; change in water inflow; change in wind speeds (Nordic countries, 2000 - 2040)	Net change in electricity supply in 2040: 1.8%. Change in electricity demand: 1.4%. Change in electricity price: -1.0%	4	1
(DOE, 2009)	PE	Drought scenario (Western Electric Coordinating Council, USA, 2010 – 2020)	In 2020, 3.7% reduction in coal generation; 43.4% increase in NG gen; 29.3% reduction in hydro gen. Production cost increase of $3.5 billion. Average monthly electricity prices up 8.1% (Nov) to 24.1% (Jul).	1	1

Note: The regions indicated in the ‘Regions’ column vary in size and are model-specific.

Table 10-4: Observed normalized insured losses from weather hazards.

Region / peril accounted for in normalized insured losses	Observation period	Trend (aggregation mode)	References
World / all weather-related	1990-2008	No trend (annual aggregates)	[1]
Australia / aggregate of bushfire, flood, hailstorm, thunderstorm, tropical cyclone	1967-2006	No trend (annual aggregates)	[7]
Germany / all weather-related Germany / floods Germany / convective events Germany / winter storms	1980-2008 1980-2008 1980-2008 1980-2008	Positive trend (annual aggregates) No trend (annual aggregates) No trend (annual aggregates) Positive trend (annual aggregates)	[1]
Southwest Germany / hailstorm	1986-2004	Positive trends in annual frequency of days exceeding thresholds of damage claim counts. Increase in annual count of hail damage claims.	[8]
Spain / floods	1971-2008	No trend (annual aggregates)	[2]
USA / winter storms (ice storms, blizzards and snow storms)	1949-2003	Positive trend (pentade totals) Positive trend (average loss per state, pentade totals)	[3]
USA / all flood ("flood only" and floods specifically caused by convective storms, tropical cyclones, snow-melt)	1972-2006	Positive trend (annual aggregates)	[4]
USA / tropical cyclones	1949-2004	Increase (7-year totals) No statistical trend assessment.	[5]
USA / hailstorm	1951-2006	Focus on top-ten major hail storm losses of the period 1951-2006. Increase in frequency and loss in the 1992-2006 period as compared to 1951-1991. No statistical trend assessment.	[6]
USA east of 109° W / convective events (hail, heavy precipitation and flash flood, straight-line wind, tornado)	1970-2009 March to September	Standard deviation (variability) by 65% greater for 1990-2009 than for 1970-1989. Mean annual loss by 167% greater for 1990-2009 than for 1970-1989. Data: normalized insured loss exceeding US$ 150 million per event, annual aggregates.	[9]
USA / all weather-related USA / floods USA / convective events USA / winter storms USA / tropical cyclones USA / heat episodes USA / cold spells	1973-2008 1973-2008 1973-2008 1973-2008 1973-2008 1973-2008 1973-2008	Positive trend (annual aggregates) Positive trend (annual aggregates) Positive trend (annual aggregates) Positive trend (annual aggregates) Positive trend (annual aggregates) Positive trend (annual aggregates) No trend (annual aggregates)	[1]

References: [1] (Barthel and Neumayer, 2012); [2] (Barredo *et al.*, 2012); [3] (Changnon, 2007); [4] (Changnon, 2008); [5] (Changnon, 2009a); [6] (Changnon, 2009b); [7] (Crompton and McAneney, 2008); [8] (Kunz *et al.*, 2009); [9] (Sander *et al.*, planned 2013).

Table 10-5: Climate change projections of insured losses and/or insurance prices.

Hazard/ insurance line	Region	Changes in future time slice(s) relative to current or control climate*			
Winter storm/ Homeowners' insurance**	 Europe in general France Belgium/Netherlands UK/Ireland Sweden/Norway Germany North Rhine-Westphalia Switzerland Poland Portugal/Spain	2021-2050 - +2% to +9% A1B [5] +4% to +7% A1B [5] +6% to +13% A1B [5] - +5% to +18% A1B [5] - - +2% to +12% A1B [5] -4% to -2% A1B [5]	End of 21st century +44% A2 [18] +6% to +47% A1B, A2 [5;14;18] +8% to +80% A1B, A2 [5;18] +17% to +43% A1B, A2 [4;5;13;14;18] +7% to +95% A1B, A2 [14;18] +15% to +114% A1B, A2 [5;13;14;18] +8% to +19% A1B, A2 [15] +19% A2 [18] -23% to +12% A1B, A2 [5;18] -10% to -5% A1B, A2 [5;14]		[4] [5] [13] [14] [15] [18]
Winter storm/ Homeowners' insurance**	Germany	2011-2040 +1.2% A1B	2041-2070 +17% A1B		[7]
Winter storm/ Homeowners' insurance**	 Europe in general France Belgium Netherlands UK Ireland Norway Denmark Germany	End of 21st century RP shift: 5 2.7, 10 5.1, 20 9.5, A2 [16] Return level change: RP10: +23%, RP30: +50%, RP100: +104%, A2 [18] RP shift: 5 2.5, 10 4.3, 20 7.4, A2 [16] RP shift: 5 2.5, 10 4.6, 20 8.5, A2 [16] RP shift: 5 2.6, 10 4.9, 20 9.1, A2 [16] RP shift: 5 3.2, 10 6.6, 20 13.9, A2 [16] RP shift: 5 4.1, 10 8.2, 20 16.1, A2 [16] Significant lengthening of RPs: 1 – 2, A2 [16] RP shift: 5 2.9, 10 5.6, 20 10.9, A2 [16] RP shift: 5 2.7, 10 4.6, 20 7.7, A2 [16]			[16] [18]
Winter storm/ Homeowners' insurance**	Germany	2011-2040 Return level change: RP10: +6% to +35% RP25: -10% to +26% RP50: -23% to +23%	2041-2070 Return level change: RP10: +20% to +30% RP25: +5% to +41% RP50: -8% to +50%	2071-2100 Return level change: RP10: +40% to +45% RP25: +45% to +58% RP50: +50% to +55%	[10]
		Ensemble of three downscaling approaches, A1B: dynamical, dynamical-statistical, and statistical.		Two downscaling approaches, A1B: dynamical and dynamical-statistical.	
Winter storm and hailstorm/ Homeowners' insurance**	Germany	2011-2040 +6% A1B Return level change: RP10: +12%, RP20: +12%, RP50: +9%	2041-2070 +26% A1B Return level change: RP10: +19%, RP20: + 6%, RP50: - 7%		[7]
Hailstorm/ Homeowners' insurance**	Germany	2011-2040 +15% A1B	2041-2070 +47% A1B		[7]
Hailstorm/ Agricultural insurances**	Netherlands	2050s, i.e. +1°C (+2°C) global mean temperature Outdoor farming insurance +25% to +29% (+49% to +58%) Greenhouse horticulture insurance +116% to +134% (+219% to +269%)			[2]
Hurricane/ All insurance lines affected by tropical cyclone	USA	End of 21st century ECHAM5/MPIOM A2: RP shift: 10 13, 20 30, 50 130 MRI/JMA A1B: RP shift: 10 7.7, 20 16, 50 52 (contrarious model results render loss estimates impossible)			[17]

damages**					
Hurricane/ Homeowners' insurance***	Florida/USA	Insurance price level change (strained reinsurance capacity): 2020s -20% to +5% (current adaptation)	 2040s -28% to +10% (current adaptation)		[12]
		Upgrade to full adaptation (85% of homes meet FL Building Code 2004): -61% to -51%	 -66% to -44%		
Typhoon/ Property insurance**	China	+2°C global mean temperature (2040s according to A1B/A2): +20%. Return level change: RP100: +7%, RP200: +14%.	+4°C global mean temperature (2070s according to A1FI): +32%. Return level change: RP100: +9%, RP200: +17%.		[4]
River flood/ Homeowners' flood insurance**	Germany	2011-2040 +84% [8] RP shift: 50 25 [6]	2041-2070 +91% [8] RP shift: 50 17 [6]	2071-2100 +114% [8] RP shift: 50 17 [6]	[6] [8]
		Seven member dynamical downscaling ensemble (B1,A1B,A2)			
Flood/ Property insurance (assumed)**	The Netherlands	2040 +125% relative to 2015 (corresponding to +24cm SLR)	2100 +1,784% relative to 2015 (corresponding to +85cm SLR)		[1]
Flood/ Property insurance**	United Kingdom	+2°C global mean temperature (2040s according to A1B/A2) +8%. Return level change: RP100: +18%, RP200: +14%.	+4°C global mean temperature (2070s according to A1FI) +14%. Return level change: RP100: +30%, RP200: +32%.		[4]
Rainfall, melting snow/ Homeowners' insurance**	Transect of three counties across southern Norway (Akershus, Buskerud, Hordaland)	End of 21st century +10% to +21% A2 +17% to +32% B2			[9]
Rainfall/ property and business interruption insurances**	Four city areas in Ontario, Canada (Ottawa, Toronto, Kitchener-Waterloo, London)	2016-2035 +13%	2046-2065 +20%	2081-2100 +30%	[3]
		Five member ensemble comprising IS92a, A2/B2, A2 scenarios			
Climate-related storms, pests, diseases/ Paddy rice insurance**	Japan	End of 21st century Paddy rice insurance payouts will decrease by 13%, on the basis of changes in standard yield and yield variability.			[11]

*Percentages indicate changes in mean annual loss ratio or absolute loss. For confidence intervals see the publications. Return period (RP) shifts identify changes in return period per loss level, return level changes identify changes in loss level per return period. RP<years>, e.g. RP100, denotes the return period of length <years>, e.g. 100 years.
**Spatial distribution and damage susceptibility of insured values assumed to be unchanged over time.
***Spatial distribution of insured values assumed to be unchanged over time; change of damage sensitivity possible.
References: [1] (Aerts and Botzen, 2011); [2] (Botzen *et al.*, 2010b); [3] (Cheng *et al.*, 2012); [4] (Dailey *et al.*, 2009); [5] (Donat *et al.*, 2011); [6] (German Insurance Association, 2011); [7] (Gerstengarbe *et al.*, 2013); [8] (Hattermann *et al.*, planned 2013); [9] (Haug *et al.*, 2011); [10] (Held *et al.*, planned 2013); [11] (Iizumi *et al.*, 2008); [12] (Kunreuther *et al.*, 2012); [13] (Leckebusch *et al.*, 2007); [14] (Pinto *et al.*, 2007); [15] (Pinto *et al.*, 2009); [16] (Pinto *et al.*, 2012); [17] (Raible *et al.*, 2012); [18] (Schwierz *et al.*, 2010).

Table 10-6: Supply-side challenges and sensitivities.

Challenges that increase in the climate change context	Example / Explanation
Failure to reflect temporal changes in hazard condition in risk management	After the devastating 2004 and 2005 hurricane seasons, the losses of Florida's homeowners' insurance accumulated since 1985 exceeded the cumulative direct premiums earned by 31%. Consequence of the upswing and peak in hurricane activity: One insurer liquidated, two seized by regulation due to insolvency; reduced coverage availability in high-risk areas [9].
Misguided incentives additionally increasing risk	US National Flood Insurance Program (NFIP) allows for a vicious circle of built-up areas already existing within flood plains pressing authorities to construct or improve protecting levees which in turn lead to even more development attracted by NFIP premium discounts, although exposed to extreme flooding events [11;20] [(IPCC, 2012)]. Additionally, older properties situated within flood plains and accounting for 16% of losses in the period 1978-2008 pay premiums substantially below the risk-adequate level [1;6;7;11;13;14]. These features represent incentives to not reduce individual flood risk adequately. Policy holders residing in flood plains where flood cover was made precondition for mortgage drop the cover after only two to four years, accounting for missing insurance penetration and insufficient built-up of NFIP risk capital [11;13;14]. All these features, together with some others, account for the fact that NFIP has continuously been running a cumulative operating deficit, reaching more than US$ 20bn after the big hurricanes of 2006 [6;7;13;14].
Non-quantifiable uncertainties increasing risk	There is ambiguity as to what degree climate change may modify regional weather hazards – model projections are not unequivocal [2;3], and there is uncertainty about prospects of post-disaster regulatory/jurisdictional pressures, e.g. to extend claims payments beyond the original coverage [9]. Such uncertainties materialize in risk-based capital loadings [12].
Liability insurance impacted by new climate risk	Chances for success of litigation in the USA where damages from greenhouse gas emissions are sought seem small, due to legal obstacles [4;5;8;17], although fractional emissions allocation schemes and theories of continuous damage triggering are being discussed [16;19]. But defense costs can be high and may be covered by liability insurance [19]. As CO_2 emissions were declared pollution (US Supreme Court/EPA), regulation on limits for CO_2 emissions is ongoing and non-compliance could impose liability for CO_2 emissions in the near future, which will be covered by liability insurance. This pending risk has not yet been adequately taken into account, as was the case with escalating environmental liability claims in the late twentieth century [10;15]. The Supreme Court of Virginia ruled on 20 April 2012 that the intentional emissions of greenhouse gases by a specific energy company according to the plaintiffs contributed to global warming and damages such as that suffered by the Inupiat village of Kivalina. Hence, this damage could not be viewed as accident and would therefore not be covered by liability insurance [18].

References: [1] (Burby, 2006) [2] (Charpentier, 2008); [3] (Collier *et al.*, 2009); [4] (Ebert, 2010); [5] (Faure and Peeters, 2011); [6] (GAO, 2010); [7] (GAO, 2011); [8] (Gerrard, 2007); [9] (Grace and Klein, 2009); [10] (Hecht, 2008); [11] (Kousky and Kunreuther, 2010); [12] (Kunreuther *et al.*, 2009); [13] (Michel-Kerjan, 2010); [14] (Michel-Kerjan and Kunreuther, 2011); [15] (Mills, 2009); [16] (Patton, 2011); [17] (Stewart and Willard, 2010); [18] (Supreme Court of Virginia, U.S.A., 2012); [19] (Taylor and Tollin, 2009); [20] (Zahran *et al.*, 2009).

Table 10-7: Products and systems responding to changes in weather risks.

Response option	Example/Explanation
Risk-adjusted premiums convey the risk to the insureds, encouraging them to adaptive measures	Insurance flood hazard zoning systems, e.g. HORA (Austria), SIGRA (Italy), and ZÜRS (Germany), hamper development in high-risk zones that lead to higher premiums [23]. Prior to Germany's disastrous River Elbe flood in 2002, 48.5% of insured households had obtained information on flood mitigation or were involved in emergency networks and 28.5% implemented one of several mitigation measures compared with 33.9% and 20.5%, respectively, of uninsured households [37].
Conditions of insurance policies incentivizing vulnerability reduction	Premium discounts for compliance with local building codes or other prevention options [24;39]; share of the insured in claims payment by deductibles or upper coverage limits, and exclusion of systematically affected property [1;6;7;8;9;12;18;37]; long-term natural-hazard insurance tied to the property and linked to mortgages and loans granted for prevention measures [24;25;33]. The latter is contested by modelled high risk capital requirements and ambiguity loadings, rendering multiyear policies relatively expensive and less flexible for the insurance market [31].
Amplifying factors in large disaster losses included in risk models	Evacuation and systemic economic catastrophe impacts, adversely affecting regional workforce and repair capacity, or knock-on catastrophes following initial catastrophes, e.g. long-term flooding following hurricane landfall [35].
Diversifying large disaster risk across securitization markets	Following the hurricane disasters of 2004 and 2005, securitisation instruments, e.g. catastrophe bonds, industry loss warranties and sidecars, acquired greater prominence, and have been recovering again from the market break in 2008 [13;15;17]. Investors in insurance linked securities are attracted by the lack of correlation to typical financial market risks (e.g., currency risks), and the well defined loss-per-index structure. The higher transparency relative to other asset-backed securities, such as mortgage-backed securities, contributed to the better performance of catastrophe bonds following the financial crisis of 2007/2008 [13;15]. As bonds typically cover large losses, the basis risk, i.e. suffering damage without parametric triggering, is not substantial [38]; further reduction may be feasible by optimizing index measurements [13]. Weather derivatives are further instruments used to transfer risks to the capital markets [14;27;34]. Also multiple-trigger "hybrid" products are available, combining a parametric trigger-based catastrophe bond with a trigger-based protection against a simultaneous drop in stock market prices, thereby hedging against a double hit from direct disaster loss and losses incurred by the asset management side [4;15;28].
Index-based weather crop insurance products	Agricultural insurances predominantly cover crop, but also livestock, forestry, aquaculture, and greenhouses. Main products are indemnity-based crop insurance (covers for single perils and multiple peril events), and index-based crop insurance [36]. The latter is available in 40% of middle-income countries, with enlarged systems beyond pilot implementation in India and Mexico [20;30]. Risk-based price signals may better foster adaptation if schemes are coupled with access to advanced technology, e.g. drought-resistant seed [3;12;20;30]. Various index definitions (cumulative rainfall, area-yield, etc.) and applications exist or have been proposed [3;26;27;29]. Adjusting to uncertain regional changes in temporal hazard condition is a basic challenge with climate change [11;21;26].
Improvements in index-based weather insurance	Basis risk can be reduced if the index scheme is applied to an area-yield trigger in a region with homogeneous production potential (e.g., based on a sample) and/or to the uppermost disaster risk layer only [11;12;19]. It can be better absorbed if index insurance works at aggregate level, e.g. to cover crop-credit portfolios or cooperatives, and if satellite-based remote-sensing technology can once be used to establish plot identification, yield estimation and loss assessment [19]. Pooling local schemes across climate regions under one cooperative parent organization, thus realizing central management, economics of scale and risk diversification, can reduce capital requirements and advance performance [5;10;32]. The disaster risk layer and high start-up costs (weather-data collection, risk modelling, education) necessitate subsidies from the state or donors [12;30].
Sovereign insurance schemes	Economic theory about the public sector's risk neutrality argues (i) that risks borne publicly render the social cost of risk-bearing insignificant and (ii) that disaster loss is seen small in comparison with a government's portfolio of diversified assets [2]. This theory proved inadequate if applied to relatively vulnerable small-sized middle to low-income countries [16], thereby rehabilitating sovereign insurance. For the Caribbean scheme CCRIF, that pools states, the reduction in premium cost per country is expected to be 45–50% [29]. Pooling natural catastrophe risks across an array of megacities has also been proposed, but not yet implemented [22].

References: [1] (Aakre *et al.*, 2010); [2] (Arrow and Lind, 1970) [3] (Barnett *et al.*, 2008) [4] (Barrieu and Loubergé, 2009) [5] (Biener and Eling, 2012); [6] (Botzen and van den Bergh, 2008) [7] (Botzen and van den Bergh, 2009) [8] (Botzen *et al.*, 2009) [9] (Botzen *et al.*, 2010a) [10] (Candel, 2007); [11] (Clarke and Grenham, 2012); [12] (Collier *et al.*, 2009); [13] (Cummins, 2012); [14] (Cummins and Mahul, 2009); [15] (Cummins and Weiss, 2009); [16] (Ghesquiere and Mahul, 2007); [17] (Guy Carpenter, 2011); [18] (Hecht, 2008); [19] (Herbold, planned 2013); [20] (Hess and Hazell, 2009); [21] (Hochrainer *et al.*, 2010); [22] (Hochrainer and Mechler, 2011); [23] (Kron, 2009); [24] (Kunreuther *et al.*, 2009); [25] (Kunreuther and Michel-Kerjan, 2009); [26] (Leblois and Quirion, 2011); [27] (Leiva and Skees, 2008); [28] (Leurig, 2011); [29] (Linnerooth-Bayer and Mechler, 2009); [30] (Mahul and Stutley, 2010); [31] (Maynard and Ranger, 2012); [32] (Meze-Hausken *et al.*, 2009); [33] (Michel-Kerjan and Kunreuther, 2011); [34] (Michel-Kerjan and Morlaye, 2008); [35] (Muir-Wood and Grossi, 2008); [36] (Swiss Re, 2013a); [37] (Thieken *et al.*, 2006) [38] (Van Nostrand and Nevius, 2011); [39] (Ward *et al.*, 2008);.

Table 10-8: Governance, public-private partnerships, and insurance market regulation.

Structural element	Example/Explanation
Public-private arrangements involving government intervention on the non-diversifiable disaster risk portion	Systems with government intervention range from ex ante risk financing design, such as public monopoly natural hazard insurance (e.g. Switzerland, with inter-cantonal pool) or compulsory forms of coverage to maximize the pool of insureds (e.g. Spain, France, with unlimited state guarantee on top), to ex post financing design, such as taxation-based governmental relief funds (e.g. Austria, Netherlands). In between these boundaries rank predominantly private insurance markets, in several countries combined with governmental post-disaster ad hoc relief (e.g. Germany, Italy, UK, Poland, USA) [16]; see also [1;4;5;13;14;15;18].
Care for people who cannot afford insurance (any more)	Either by funds outside the insurance system, e.g. insurance vouchers [8], or by premium subsidies (particularly for the catastrophic risk portion) [1;8;18;20].
Public-private partnership to expedite agricultural development	Insurance improve the farmers' creditworthiness that in turn strengthens their adaptive capacity. For instance, by means of loans farmers can step from low-yield to higher-yield cropping systems [3;9;10].
Proposals for adaptation-oriented climate change risk management frameworks to UNFCCC	Risk prevention and risk reduction is the starting point (AOSIS, Switzerland and MCII) that can absorb many of the smaller weather risks, and various forms of insurance are meant to cover all of the remaining risks [2;9;11;12;17;19]. The global framework, where the wealthy agree to pool risks with the most vulnerable, equals social insurance that is different from a risk-based share in insurance funds [6].

References: [1] (Aakre *et al.*, 2010); [2] (AOSIS, 2008); [3] (Barnett *et al.*, 2008); [4] (Botzen and van den Bergh, 2008); [5] (Bruggeman *et al.*, 2010); [6] (Duus-Otterström and Jagers, 2011); [7] (Kovacevic and Pflug, 2011); [8] (Kunreuther *et al.*, 2009); [9] (Linnerooth-Bayer *et al.*, 2009); [10] (Mahul and Stutley, 2010); [11] (MCII, 2008); [12] (MCII, 2012); [13] (Monti, 2012); [14] (Paudel, 2012); [15] (Schwarze and Wagner, 2007); [16] (Schwarze *et al.*, 2011); [17] (Swiss Confederation, 2008); [18] (Van den Berg and Faure, 2006); [19] (Warner and Spiegel, 2009); [20] (Zhu, 2011).

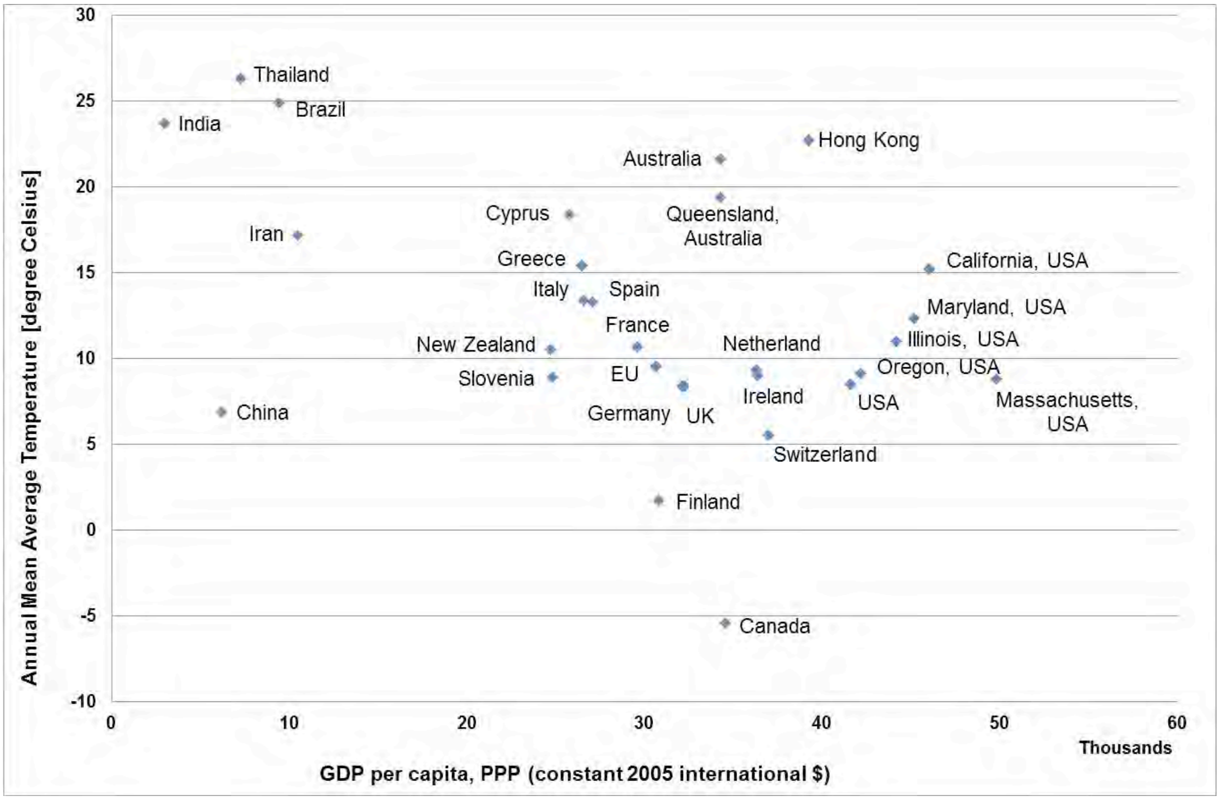

Figure 10-1: GDP per capita (in 2009) and annual mean temperature (based on 1971-2000 climatology) in selected countries and US federal states. Source: Toth, (2013). Note: PPP: purchasing power parity.

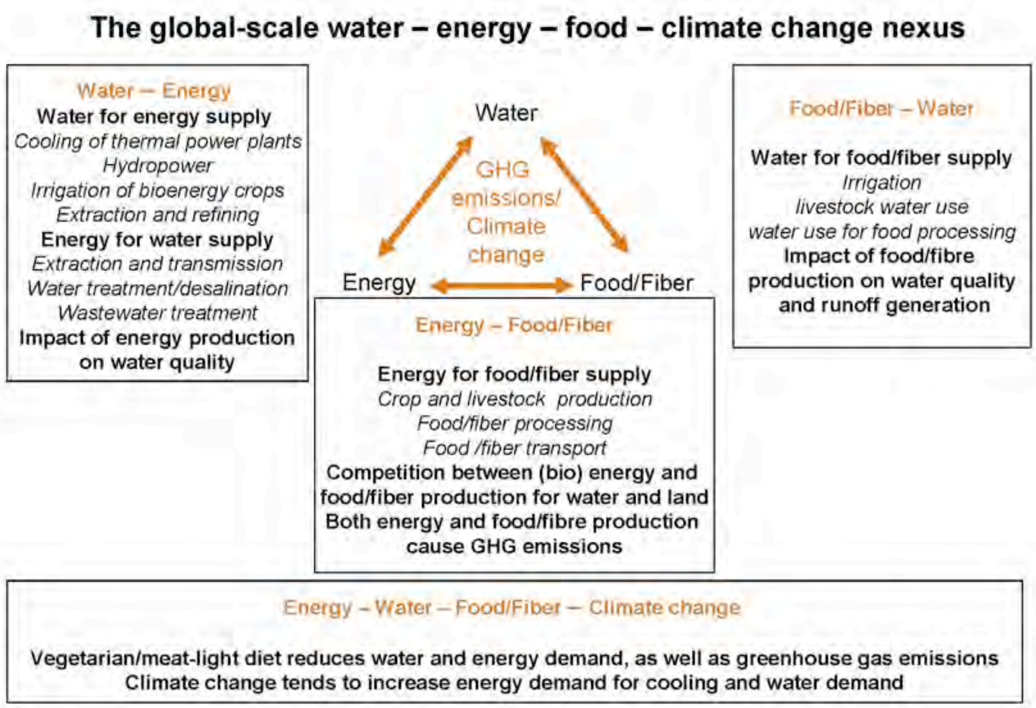

Figure WE-1: The water-energy-food nexus as related to climate change.