1. Introduction

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BUILDING A CLIMATE RESILIENT ECONOMY AND SOCIETY

Climate change poses a great challenge to governments, societies and entities. Finding ways to transit to a climate resilient economy and society therefore assumes great importance. Average global atmospheric CO_2 concentration has increased from the pre-industrial level of 280 parts per million (ppm) to 400.8 ppm in 2015. The annual growth rate of atmospheric carbon dioxide has roughly tripled from 0.6 ppm per year in the early 1960s to an average of 2.1 ppm during the past ten years, and further rose to a high of 3.05 ppm in 2015 according to observations recorded at the Mauna Loa Observatory, Hawaii (NOAA, 2016). Global CO_2 emissions rose from about 22.5 billion tons in 1990 to 35.7 billion tons in 2014 (Table 1.1). While developed countries such as the USA, EU 28, Japan, Australia and Canada put together accounted for about 30.7 per cent of the total global CO_2 emissions in 2014, China's share alone was about 29.7 per cent (Table 1.1). Although fast growing economies such as India have witnessed a rapid rise in CO_2 emissions recently, in per capita terms India's CO_2 emissions (1.8 tons per capita) are still far below those prevailing in developed countries, which ranged between 10 and 17.3 tons per capita in 2014 (Table 1.1).

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) presents a grim picture of the trends in climatic variables. Its key findings, amongst others, note as follows (IPCC, 2014a):

- Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases (GHGs) are the highest in history. Anthropogenic GHG emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever.
- Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period

Table 1.1 Share of selected countries in CO_2 emissions and per capita CO_2 emissions (1990 and 2014)

Country	Share in CO_2 emissions in % 1990	Share in CO_2 emissions in % 2014	CO_2 emissions in tons per capita 1990	CO_2 emissions in tons per capita 2014
China	10.7	29.7	2.1	7.6
USA	22.2	14.8	19.6	16.5
EU 28	19.1	9.5	9.2	6.7
India	3.1	6.4	0.8	1.8
Russia	10.7	5.0	16.1	12.4
Japan	5.3	3.6	9.6	10.1
Canada	1.8	1.7	16.2	15.9
Brazil	0.9	1.4	1.5	2.5
Australia	1.3	1.1	16.1	17.3
South Africa	1.3	1.1	7.3	7.4
Global total	22.5 billion tons of CO_2	35.7 billion tons of CO_2		

Source: Olivier et al. (2015).

from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere where such assessment is possible (*medium confidence*).

- The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 (0.65 to 1.06) °C over the period 1880 to 2012.
- Global mean sea level rose by 0.19 m (0.17 to 0.21 m) between 1901 and 2010. The rate has been higher since the mid-19th century as compared to the previous two millenniums (*high confidence*).
- Over the period 1992 to 2011, the Greenland and Antarctic ice sheets lost mass (*high confidence*), likely at a greater rate over 2002 to 2011.
- Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level will continue to rise.
- A large fraction of species face increased risk owing to climate change during and beyond the 21st century, especially as climate change interacts with other stressors (*high confidence*). The Fourth

> Assessment Report of the IPCC notes that globally approximately 20 to 30 per cent of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5 °C (relative to 1980–1999 temperature levels). As global average temperature increase exceeds about 3.5 °C, model projections suggest significant extinctions, that is, 40 to 70 per cent of species assessed (IPCC, 2007).

If these trends continue, which is most likely, and exacerbate further in the absence of efforts to stabilize emissions, it will have disastrous consequences on human and natural systems. Economic estimates of the costs of climate change vary widely across different studies, countries and regions depending upon the assumptions made regarding future emission scenarios, period of analysis, discount rate used, and so on. The Stern Review (Stern, 2007) suggests that, if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5 per cent of global gross domestic product (GDP) each year, now and for ever. If a wider range of risks and impacts is considered, the estimates of damage could rise to 20 per cent of GDP or more (Stern, 2007). However, the Stern Review estimates were widely criticized. Tol and Yohe (2006), for instance, note that the estimates in the Stern Review were based on existing published literature and were on the lower side (losses below 5 per cent of GDP). Further the high valuation of climate change impacts in the Stern Review were due to the use of a very low discount rate, risk that is double counted, and vulnerability that is assumed to be constant over very long periods of time (two or more centuries, to be exact). A review of estimates by different researchers notes that, based on assumptions made regarding future emission scenarios and for other parameters, for warming levels of between 1 and 3 °C the impact on GDP ranged from 2.5 per cent to −4.8 per cent (Tol, 2009). These estimated losses in GDP were much higher for Africa, Asia and South America, ranging from −2.6 per cent to −23.5 per cent across different studies (Tol, 2009). A recent study by Ahmed and Suphachalasai (2014) notes that, without global deviation from a fossil fuel intensive path, South Asia could lose an equivalent of 1.8 per cent of its annual GDP by 2050, which will progressively increase to 8.8 per cent by 2100 on the average under a business as usual (BAU) scenario. The Fifth Assessment Report of the IPCC notes that economic impact estimates completed over the past 20 years vary in their coverage of subsets of economic sectors and depend on a large number of assumptions, many of which are disputable, and many estimates do not account for catastrophic changes, tipping points, and many other factors. With these recognized limitations, the incomplete estimates of global annual economic losses for additional temperature increases of ~2 °C are between 0.2 and 2.0 per cent of income (±1 standard deviation around the mean) (*medium evidence*, *medium agreement*). Losses are *more likely than not* to be greater, rather than smaller, than this range (*limited evidence*, *high agreement*). Additionally, there are large differences between and within countries. Losses accelerate with greater warming (*limited evidence*, *high agreement*), but few quantitative estimates have been completed for additional warming around 3 °C or above (IPCC, 2014b).

To address the risks (e.g. hazards and extreme weather events) posed by climate change we need to build the resilience of people, areas and sectors to cope with these risks. Climate resilience can be generally defined as the capacity of a socio-ecological system to: (1) absorb stresses and maintain function in the face of external stresses imposed upon it by climate change; and (2) adapt, reorganize and evolve into more desirable configurations that improve the sustainability of the system, leaving it better prepared for future climate change impacts (Folke, 2006; Nelson et al., 2007). The IPCC (2014b) defines 'resilience' as 'the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation'. To implement policies to enhance climate resilience we need to assess the vulnerability of people, areas and sectors to the risks posed by climate change. Vulnerability encompasses three components, namely adaptive capacity, exposure and sensitivity. Different approaches such as historical narratives, geographical information system (GIS) and mapping techniques, agent-based modelling and an indicator-based approach have been used to assess vulnerability to climate change (Panda, 2016). Of these, indexes of vulnerability based on socio-economic, biophysical and other parameters have been popular and used by researchers, for example, to assess the vulnerability of coastal communities in Vietnam (Adgers, 1999) and the vulnerability to climate change of people living in drought-prone areas in Odisha, India (Panda, 2016). Poor and marginalized people, indigenous communities, and coastal communities, ecologically fragile areas such as hill and dry regions, coastal areas, and agriculture and the primary sector are most vulnerable to the adverse effects of climate change. Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change (IPCC, 2014a). Mitigation implies that the causes of climate change are addressed by reducing GHG emissions, whereas adaptation requires that the effects of climate change are dealt with by coping with their negative impacts. Substantial emission reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate resilient pathways for sustainable development (IPCC, 2014a). Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices (IPCC, 2014a).

The historic climate pact approved by 195 countries attending the 21st Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris (30 November to 11 December 2015) provides a roadmap to the global community to inch towards a climate resilient economy and society. The agreement, which comes into effect from the year 2020, resolved to limit the global temperature increase to well below 2 °C above pre-industrial levels and pursue efforts to limit temperature rise to 1.5 °C above pre-industrial levels if possible. It further agreed that, while rich countries would engage in absolute emission reductions, developing countries would enhance mitigation efforts. The accord also agreed to periodic monitoring and verification of all countries' GHG inventory and emission reductions. It agreed to mobilize climate finance of US$ 100 billion per year by 2020 to 2025 and a new higher goal thereafter to assist developing countries in reducing emissions and adapting to climate change. Following its ratification by the requisite number of countries in accordance with Article 21, Para 1, the Paris Climate Agreement came into force with effect from 4 November 2016 (UNFCCC, 2016).

Need for Building Climate Resilience

An obvious question that arises is why we need to build climate resilience. The risks arising from climate change are many, such as unforeseen and extreme weather events like heat waves, typhoons and cyclones, coastal and river flooding, prolonged droughts, and so on. These can have adverse economic, social and environmental consequences and affect human well-being and the overall quality of life. For instance, it is estimated that between 1980 and 2014 weather-related losses were estimated at US$ 3.3 trillion (2014 values adjusted for inflation based on country CPI), of which only about 28.5 per cent was insured, that is, US$ 0.94 trillion (Munich RE, 2015). Some 88 per cent of these reported disasters (total 21,700 disaster events), 78 per cent of total losses from all disasters (US$ 4.2 trillion expressed in 2014 values) and 49 per cent of lives lost (total lives lost from all disasters being 1.74 million) were caused by weather extremes (Munich RE, 2015). It is also estimated that large coastal cities alone could face combined annual losses of US$ 1 trillion from flooding by mid-century (cited in Royal Society, 2014). Hence we need to be well prepared to cope with such eventualities. Further rising temperatures, shrinking of mountain glaciers and variations in other climatic parameters have led to diseases or their carriers reaching higher elevations or the emergence of new diseases such as dengue. Increasingly, these factors are driving new and unpredictable patterns in the spread of common water- and vector-borne diseases, with conventional protocols for monitoring and managing them under increasing strain (Dayal, 2014). A recent study by the Asian Development Bank (ADB) suggests that under low, medium and high emission scenarios (B1, A1B and A2 SRES scenarios of the IPCC) the number of people in India who would be affected by malaria by 2050 is estimated to range between 1.71 million and 3 million, and the number of deaths due to malaria is estimated to range between 0.01 million and 0.12 million (Ahmed and Suphachalasai, 2014). Similarly, the number of people in India who will be affected by diarrhoea by 2050 is estimated to range between 24.3 million and 42.4 million under low, medium and high emission scenarios (Ahmed and Suphachalasai, 2014). Building climate resilience is therefore essential to tackle these emerging public health challenges and rising health costs. Renewable surface water and groundwater resources in most dry subtropical regions are projected to reduce owing to climate change, intensifying competition for water among sectors (IPCC, 2014a). This will aggravate conflicts between households, sectors and regions over access to and use of shrinking water resources. Climate change may also lead to transboundary conflicts (e.g. over access to and use of water resources) or movement of environmental refugees (Cammack, 2007). Rising demand for food due to rising population and incomes coupled with declining production of staples such as wheat, rice and maize due to the adverse effects of climate change will undermine food security and affect the poor and vulnerable people. Mainstreaming 'resilience' into development plans is therefore critical to tackling poverty, inequality, ill health and poor sanitation, as well as realizing the Sustainable Development Goals (SDGs), since poor and marginalized people and poor countries that have low adaptive capacity are most vulnerable to the adverse consequences of climate change. Improving risk management can lead to larger gains in development and poverty reduction (World Bank, 2013a). Implementing climate and disaster resilient development plans may entail high start-up costs, but they are cost effective in the long run and could reduce the costs due to disaster. Early warning systems, better preparedness and improved safety codes have proven to be cost effective, save human lives and protect public and private investment (World Bank, 2013b). For instance, Cyclone Phailin, which struck Odisha and Andhra

Pradesh states on the east coast of India in October 2013, resulted in 40 deaths only, compared to the 10 000 who perished during a similar event in 1999 in the absence of such early warning systems (World Bank, 2013b). Building climate resilience will also be helpful in coping with uncertainties arising from the complex and dynamic interactions between climate change and other parameters such as health.

Approaches to Build Climate Resilience

There are a number of approaches to build climate resilience. These are ecosystem-based, engineering-based, hybrid (i.e. a combination of ecosystem- and engineering-based), social and behavioural approaches (Royal Society, 2014). Table 1.2 gives examples of using these adaptation options to address extreme weather events such as heat waves, coastal flooding, droughts and river flooding. For instance, an ecosystem-based approach involves building resilience through green solutions such as afforestation or reforestation to capture carbon, encouraging coastal afforestation and maintaining or re-establishing mangroves to reduce the impact of coastal flooding and storm surges, maintaining and increasing tree cover in cities and towns to reduce the consequences of heat waves, promoting agro-forestry in drought-prone areas, and so on. An engineering-based approach includes investing in human-made structures such as building sea walls or coastal barrages to cope with sea level rise and coastal erosion, building cyclone shelters in cyclone-prone areas, and so on. A hybrid approach involves combining ecosystem- and engineering-based approaches to address weather extremes and disasters. For example, to build resilience against sea erosion, sea level rise and storm surges one could construct sea walls or coastal barrages along with planting trees in coastal boundaries prone to such problems. A social approach involves building and strengthening social networks and community-led responses and actions to adapt to climate change. A behavioural approach involves transforming the mindset, attitudes and values of people in order to change their lifestyles and take proactive actions that will help address the adverse effects of climate change. These are not mutually exclusive approaches and could complement each other. For instance, community-led responses and actions to address the ill effects of climate change would entail a change in the attitudes and values of individuals and communities. These approaches have their advantages and disadvantages. For instance, an engineering-based approach requires considerable funds and capital to be invested in building human-made structures such as sea walls, cyclone shelters, and so on to mitigate the adverse impacts of climate change, whereas an ecosystem-based approach may be a low cost option. But the

Table 1.2 Examples of different ecosystem- or engineering-based or hybrid (i.e. combination of ecosystem- and engineering-based) options to reduce the impact of four types of extreme weather events

Extreme weather events	Examples
Heat waves	Afforestation; maintenance of existing vegetation; green roofs, vertical greening systems; white roofs; urban planning, grid design, etc.; air conditioning; insulation.
Coastal flooding	Maintenance of natural reefs (coral/oyster); maintenance of mangroves; mangrove planting and re-establishment; maintenance and creation of salt marshes, wetlands, inter-tidal ecosystems; maintenance of coastal, forest and other ecosystems; coastal re-vegetation and afforestation (above inter-tidal zone); beach and dune nourishment; artificial reefs; dykes, levees; coastal barrages.
Drought	Removal of thirsty invasive plant species; reforestation; forest conservation; agroforestry; breeding drought resilient crops and livestock; sustainable agroecosystem management practices; soil and water conservation; reservoirs, ponds and other water storage; wells; irrigation; inter-basin water transfer; waste-water recycling.
River flooding	Re-establishment of floodplains, green rivers; catchment afforestation, increased vegetation cover; maintenance of existing catchment vegetation; planting of riparian buffers; changes to catchment agricultural land management; natural flood management; stream habitat restoration; dams; drains, dykes, levees, sluices, pumps; dredging; sustainable urban drainage systems; canalization of urban streams.

Source: Royal Society (2014: 60–61).

ecosystem-based approach may have high opportunity costs such as the need for land to raise afforestation/reforestation, and so on (Royal Society, 2014). An engineering-based approach too could have high opportunity costs, since funds that would otherwise be used for development activities must be diverted to invest in human-made structures to combat sea level rise, coastal erosion, and so on. An ecosystem-based approach can have several co-benefits (SCBD, 2009). Table 1.3 illustrates the adaptive

Table 1.3 Examples of the co-benefits of ecosystem-based adaptation measures in response to climate change

Adaptation measure	Adaptive function	Co-benefits			
		Social and cultural	Economic	Biodiversity	Mitigation
Mangrove conservation	Protection against storm surges, sea level rise and coastal inundation.	Provision of employment opportunities (e.g. fisheries and prawn cultivation); contribution to food security.	Generation of employment opportunities to local communities through marketing of mangrove products (e.g. fish, dyes, medicines).	Conservation of species that live or depend on mangroves.	Conservation of carbon stocks, both above and below ground.
Forest conservation and sustainable forest management	Maintenance of nutrient and water flow; prevention of landslides.	Opportunities for recreation, culture, and protection of indigenous people and local communities.	Potential generation of income through ecotourism, recreation, sustainable logging.	Conservation of forest plant and animal species.	Conservation of carbon stocks; reduction of emissions from deforestation and degradation.
Restoration of degraded wetlands	Maintenance of nutrient and water flow, quality, storage and capacity; protection against flood or storm inundation.	Sustained provision of: livelihood, recreation, employment opportunities.	Increased livelihood generation, potential revenue from recreational activities; sustainable logging of planted trees.	Conservation of wetland flora and fauna, and stop-over sites for migratory species.	Reduced emissions from soil carbon mineralization.
Establishment of diverse agroforestry systems in agricultural lands	Diversification of agricultural production to cope with changed climate conditions.	Contribution to food and fuelwood security.	Generation of income from sale of timber, firewood and other products.	Conservation of biodiversity in agricultural landscapes.	Carbon storage in above and below ground biomass and soils.

Table 1.3 (continued)

Adaptation measure	Adaptive function	Co-benefits			
		Social and cultural	Economic	Biodiversity	Mitigation
Conservation of agrobiodiversity	Provision of gene pool for crop and livestock adaptation to climate change.	Enhanced food products; diversification of food products; conservation of local and traditional knowledge and practices.	Possibility of agricultural incomes in difficult environments; environmental services such as bees for pollination of cultivated crops.	Conservation of genetic diversity of crop varieties and livestock breeds.	
Conservation of medicinal plants	Local medicines available for health problems resulting from climate change or habit degradation (e.g. malaria, diarrhoea, etc.).	Local communities have an independent and sustainable source of medicines; maintenance of local knowledge and traditions.	Potential source of income for local people.	Enhanced medicinal plant conservation; local traditional knowledge recognized and protected.	Environmental services such as bees for pollination of cultivated crops.
Sustainable management of grasslands	Protection against floods; nutrient storage; maintenance of soil structure.	Recreation and tourism.	Generate income for local communities through products from grass (e.g. brooms).	Forage for grazing animals; provide diverse habitats for animals that are predators and prey.	Maintenance of soil carbon; storage of soil carbon.

Source: SCBD (2009: 43–44, table 2.3). Reproduced with permission from the SCBD, Montreal.

function and co-benefits of various adaptation options to address climate change. For instance, conservation of mangroves, which helps to protect against storm surges, sea level rise, coastal inundation, and so on, has several co-benefits, such as generating employment opportunities in fisheries, prawn cultivation, conserving mangrove-dependent species, carbon sequestration, providing a nursery for fish, and so on. Using a portfolio of approaches to address the multiple risks posed by climate change may yield greater benefits and win–win outcomes.

Challenges and Opportunities for Building Climate Resilience

Ensuring the implementation of the Paris Climate Agreement according to the agreed pledges, targets and timelines poses the biggest challenge in building climate resilience. This calls for cooperation and action at different scales (local, national and international) and among different stakeholders such as the state, local communities, civil society, and different interest groups including the private sector. Moreover the United Nations Environment Programme (UNEP) notes that even if all the emission reduction pledges made by countries in their intended nationally determined contribution (INDC) submitted to the UNFCCC are taken into account it still falls short of the emission reductions required to ensure a temperature rise of below 2 °C or a desirable 1.5 °C over pre-industrial levels by the year 2100 as resolved in the Paris Climate Agreement (UNEP, 2015). Giving favoured access to energy-efficient and other clean technologies and funding to transit to a low carbon economy and society is critical for developing countries which are still heavily dependent on fossil fuel-led growth. According to the Paris Climate Agreement developed countries pledged to raise funds to the tune of US$ 100 billion per annum by 2020 to help developing countries to adopt clean technologies and transit to a low carbon economy. But this appears to be far below the funding required for the mitigation and adaptation needs of developing countries. For instance, India's INDC submitted to the UNFCCC notes that between 2015 and 2030 India alone needs US$ 206 billion (at 2014–2015 prices) for implementing adaptation actions in agriculture, forestry, fisheries, infrastructure, water resources, and so on (UNFCCC, 2015). Estimates by India's NITI Aayog (the successor to India's former Planning Commission) indicates that the mitigation costs for moderate low carbon development would be around US$ 834 billion till 2030 at 2011 prices (UNFCCC, 2015). To give a sense of the funds needed vis-à-vis the pledges made in the Paris Climate Agreement it is worth noting that in the year 2015 US annual military expenditure was around US$ 598.5 billion; similarly, the annual global market for luxury goods was estimated at US$ 1 trillion in 2015, and for luxury cars about US$ 458 billion (Ninan, 2016). Addressing development needs as well as ensuring climate action is especially challenging for developing countries and new emerging economies which are struggling to reduce poverty levels and meet basic needs, but are still dependent on fossil fuel-led growth. Fossil fuel-dependent industries and sectors have concerns about losing their competitiveness and markets vis-à-vis the renewable energy sector. International trade and trading policies will increasingly be driven by these green constraints. Building a political consensus and will to shift from a carbon-subsidizing regime to a carbon-taxing regime is another challenge facing many countries. There is also a need for building the capacity of different actors and institutions, including different layers of government to cope with the challenges posed by climate change. Financial reforms including in the insurance sector are needed to cover the risks posed by climate change, especially owing to rising costs and strains on governmental and household finances arising from weather-related extremes and disasters, as noted earlier. Rising incomes and global population, which is projected to rise to 9.3 billion by the year 2050 from 7 billion in 2011 according to the 2010 medium projections of the UN, pose further challenges in promoting climate resilient policies (Royal Society, 2014).

The recent international agreements on climate change, disaster reduction and phasing out of hydrofluorocarbons (HFCs) and their implementation present an opportunity to develop a coherent strategy to build resilience to extreme weather locally, nationally and internationally, and to shape plans, responses and outcomes for decades to come. There is also growing recognition about the role of the natural environment in reducing hazards, and recognition of the importance of mobilizing community support (Royal Society, 2014). For instance, evidence suggests that, in the aftermath of the 2004 tsunami, areas with intact mangrove forests could withstand the huge devastation caused by the tsunami in South and South-East Asia, whereas in areas where mangroves and other coastal habitats had been destroyed, often illegally, the waves could penetrate far inland, destroying homes, inundating farmland and washing away people and livelihoods (EJF, 2006). SCBD (2009) notes that integrating biodiversity and provision of ecosystem services is cost effective, and can generate social, economic and cultural co-benefits and help maintain resilient systems. Scientific and technological advances, improvements in forecasting and warning systems, and so on have enabled states and communities to be better prepared than ever before to cope with weather extremes and disaster events. Satellite imagery and high resolution data and use of more sophisticated models provide policymakers with unprecedented access to reliable data with which to make better informed decisions (Royal Society, 2014). Smart phones are increasingly being used to transmit the latest weather forecasts to farmers, farming villages and village level institutions, which enables them to make timely decisions on the commencement date for sowing crops or to prepare for weather extremes such as droughts or floods. New crop varieties and technologies provide an opportunity to make agriculture more sustainable and climate resilient as well as meet the needs of a growing population with better incomes. Improved awareness of the risks of global warming along with scientific evidence has created a better environment for climate action and resilient-building measures at the local, national and international scales as well as among different stakeholders. Integration of indigenous, local and scientific knowledge will be helpful in taking advantage of different knowledge systems to enhance climate and disaster resilience. There is also growing availability of funding and initiatives for climate action at the national and international levels along with participation of the private sector to fund mitigation and adaptation projects in different sectors. For instance, the Global Facility for Disaster Reduction and Recovery (GFDRR), launched in 2006 and hosted by the World Bank with 21 participating donors and other stakeholders, offers a unique business model for advancing disaster risk management based on ex-ante support to high risk countries and ex-post assistance for accelerated recovery and risk reduction following a disaster (World Bank, 2013b). As of December 2012, GFDRR had provided support to over 80 countries and received US$ 342 million in pledges and contributions to implement its multi-annual work programme (World Bank, 2013b). Since 2008 the World Bank through the International Bank for Reconstruction and Development (IBRD) has been issuing Green Bonds to raise funds from investors in the capital markets to develop innovative solutions and attract private sector financing for climate action in IBRD borrowing countries, and raise awareness about climate change and the opportunities to invest in climate solutions (World Bank, 2013b). In India, the government has set up a National Adaptation Fund with initial funding of US$ 55.6 million to meet the adaptation needs of sectors such agriculture, water and forestry, in addition to sectoral spending by sector ministries (UNFCCC, 2015). India has also set up a National Clean Environment Fund to finance clean energy technologies and projects (UNFCCC, 2015). Such initiatives will enhance efforts to build a climate resilient future.

ABOUT THE BOOK

Keeping in view the above discussion, this book addresses the challenges and opportunities for building a climate resilient economy and society. The chapters included in this volume cover a broad range of topics such as vulnerability, adaptation and resilience, challenges and prospects for building climate resilience in different sectors such as agriculture, marine ecosystems, urban areas, energy and water-stressed areas, carbon pricing and financing, REDD+, climate policies and governance, among others. The chapters include those that have a global or regional focus as well as case studies drawn from a cross-section of countries in Africa, Asia, Europe and North America. The contributors to this book are leading experts from around the world who have made a significant contribution to the literature in this area. Some of them have also been part of IPCC Assessments. For convenience, the discussion in the book is organized in three parts: I, 'Vulnerability, adaptation and resilience'; II, 'Climate resilience: Sectoral perspectives'; and III, 'Incentives, governance and policy'.

Part I: Vulnerability, Adaptation and Resilience

Issues related to vulnerability, adaptation and resilience are the focus of the chapters included in Part I.

Encouraging adaptation is an essential aspect of the policy response to climate change, as noted earlier. However, given that human activities are the main cause of environmental transformations worldwide, it follows that adaptation itself also has the potential to generate further pressures, creating new threats for both local and global ecosystems. From this perspective, policies designed to encourage adaptation may conflict with regulations aimed at preserving or enhancing environmental quality. This aspect of adaptation has received relatively little consideration in either policy design or academic debate. To highlight this issue, Fezzi et al. in Chapter 2 analyse the trade-offs between two fundamental ecosystem services which will be impacted by climate change: provisioning services derived from agriculture and regulating services in the form of freshwater quality. Their results indicate that climate adaptation in the farming sector will generate fundamental changes in river water quality. In some areas, policies which encourage adaptation are expected to conflict with existing regulations aimed at improving freshwater ecosystems. These findings illustrate the importance of anticipating the wider impacts of human adaptation to climate change when designing environmental policies.

It is important to identify the factors influencing adaptive capacity among households within a community, as doing so will enable effective targeting of government interventions to address the risks posed by climate change. In Chapter 3 Panda et al. study such factors using household survey data collected from a drought-prone region of Orissa, India. In the survey respondents were asked about the adaptations that they had engaged in to deal with the risk of drought, as well as a number of indicators for adaptive capacity taken from the literature. The study found many indicators to correlate with one or more adaptations taken. However, many of these indicators, while increasing the likelihood that one adaptation would be taken, also decreased the likelihood that another would be taken, and hence were not unambiguous determinants of greater adaptive capacity in general. Access to crop insurance was found to be particularly effective: it correlated with an increased likelihood of engaging in two separate yield-raising adaptations. Their results suggest that further attention to crop insurance may be warranted, as well as further research to determine if the other indicators may be effective in other contextual settings.

Nature plays an important role in addressing the risks posed by climate change. In Chapter 4, Mutafoglu et al. explore nature's contribution to improving micro-climatic conditions in cities and mitigating urban heat stress, thereby helping cities become climate resilient. Green infrastructure, such as parks and tree-lined streets, can contribute to climate resilience and the health of urban populations by reducing heat stress, as well as hospitalizations and mortality. Today, with more than half of the global population urbanized, population densities and the heat island effect amplify heat-related risks in cities and necessitate appropriate solutions. The chapter presents a range of examples illustrating the benefits of nature, building mainly on insights from Europe. It also details how stakeholders collaborate to invest in urban and suburban green infrastructure and use a variety of tools, measures, processes and financing sources. The chapter then outlines a roadmap for moving forward.

In Chapter 5 Shandas et al. argue for using coproduction as a model for urban resilience, based on a recent collaborative project between planners and researchers. They review the findings of four collaborative workshops of neighbourhood-scale climate adaptation, using spatial and statistical analyses, as well as posit the conceptual framework underlying the project's collaborative rationality. Their assessment is from two perspectives: (1) an academic, phenomenological lens; and (2) a pragmatic lens. They argue that, in order to understand resilience, we must first ask the question 'Resilience to what and for whom?' To that end, they consider what characterizes those communities that are affected by two major urban environmental hazards, namely air pollution and urban heat, in the city of Portland, Oregon in the Pacific Northwest of the United States. Empirically, the authors explore neighbourhood level exposure to air pollution and extreme heat, as well as these spatially defined communities' physiological sensitivity to the two hazards, and their social capacity to adapt to them. Phenomenologically, the authors argue that this collaboration is an effort in *coproduction*, encapsulating cooperation between scientific experts and governmental authorities in the production of knowledge toward a socially determined goal in the public interest.

Small island developing states (SIDS) are most vulnerable to climate change. It is due to the insistence of SIDS that the Paris Climate Agreement concluded in December 2015 also set a desirable target of limiting temperature rise to 1.5 °C above pre-industrial levels. Chapter 6 by Pichs-Madruga discusses the economic, social and environmental challenges, and options for SIDS to address the risks posed by climate change, especially rising sea levels, extreme weather events and degradation of marine ecosystems with their consequent impacts on lives and livelihoods in the SIDS. Mitigation and adaptation measures, improving the sustainability of marine ecosystems and marine fisheries, disaster risk reduction and community-based approaches to development are critical to enhance climate resilience and sustainable development in SIDS.

Part II: Climate Resilience: Sectoral Perspectives

The risks posed by climate change differ across sectors, and hence policies to build climate resilience need to take account of these sectoral perspectives. In Part II the chapters focus on the challenges and opportunities for enhancing climate resilience in different sectors such as agriculture, marine ecosystems, urban areas, water-stressed regions and energy.

Agriculture is highly exposed to climate change, and much of the international climate discourse has focused on the sector's vulnerability, resilience and adaptive capacity for given projected climate scenarios. The sector also has a recognized role in terms of climate change mitigation. The agricultural sector accounts for approximately a third of total global anthropogenic GHG emissions, including emissions from land use change and deforestation (IPCC, 2014a). These climate challenges overlap a growing concern about global food security, which highlights additional stressors, including demographic changes, natural resource scarcity, and economic convergence in consumption preferences, particularly livestock products. The Food and Agriculture Organization (FAO) of the United Nations estimates that, to meet the demands of a larger population (expected to cross 9 billion by 2050), food supply will need to grow by 60 per cent. The term 'climate smart agriculture' (CSA) has been coined to describe practices, systems and institutional arrangements that balance the trade-offs inherent in meeting these objectives. Climate smart agriculture has become a focus of research in developed and developing countries. In Chapter 7, Arakelyan et al. provide a critical appraisal of the concept of CSA and review the experiences in implementing CSA in a cross-section of countries in Africa. The chapter then discusses the policies and institutional support needed to achieve climate smart agriculture as well as highlights some of the concerns regarding CSA, especially its sustainability and distributional consequences.

Rising sea levels, pollution, and increasing stresses on marine species and areas are major challenges confronting marine ecosystems as a result of climate change. In Chapter 8 Tisdell reviews the major changes in marine environments which natural scientists expect to occur because of elevated levels of GHGs in the atmosphere and considers their general implications for the presence of living organisms and supply of marine ecoservices. The chapter then focuses attention on the insights obtained from a Norwegian investigation of the economic impacts of GHG-induced changes in marine ecosystems. Thereafter GHG-induced losses of coral reefs and their potential economic impacts are discussed. Proposed policies for responding to predicted changes in marine ecosystems are examined, followed by a discussion of building resilience in the context of marine ecosystems.

Sumaila et al. in Chapter 9 review current knowledge on the potential impacts of climate change on marine ecosystems and the millions of people worldwide who depend on them. The authors highlight the fact that different parts of the world would be impacted differently and, therefore, climate will impact people in different regions differently. They then provide a number of policy recommendations to help prepare society for the changes that we are already seeing and those yet to come. To build climate resilient marine ecosystems and global fisheries, the authors highlight the need to transform their management by increasing incentives for community engagement and deploying marine protected areas, and to promote sustainability enhancing public policies by avoiding harmful ones such as the provision of capacity enhancing fisheries subsidies.

Climate change is projected to aggravate water stress in dry and arid regions. Against the backdrop of the epic drought faced by California in the USA in 2015, Chapter 10 by Miller discusses the significant vulnerabilities and options for maintaining the resilience of the state's water-dependent economic activities. The drought led to very uneven impacts on different water users and sections of the state, as well as on natural ecosystems versus managed landscapes. Differential vulnerabilities can be traced to the state's complex geography, the configuration of its water storage and delivery infrastructure, and its imperfectly administered mixture of prior appropriation and riparian surface water rights coupled with limited regulation of groundwater withdrawals. Approaches for reducing economic losses have included selective fallowing, increased groundwater pumping, adoption of water-saving irrigation techniques, and market transfers of water. The chapter highlights innovative water management strategies that have emerged over the course of the drought and the lessons that California's drought experience suggests for other areas that may face increasing drought risks in a warmer future climate.

Urban areas will face increased risks as a result of climate change such as heat stress, storms and extreme precipitation, inland and coastal flooding, air pollution, water scarcity, sea level rise, storm surges, and so on (IPCC, 2014a). By the year 2050 about 66 per cent of the world's population will reside in urban areas; much of the projected increase will take place in Asia and Africa (United Nations, 2014). Recent studies confirm that the impacts of climate change are already being seen and felt in major Asian cities. To combat the impacts of climate change, Asian city governance needs to mainstream climate change resilient policies into urban planning. Chapter 11 by Johnson et al. explores the challenge of enhancing climate resilience in two of the world's most vulnerable coastal city regions – Dhaka (Bangladesh) and Ho Chi Minh City (Vietnam). The chapter reviews the policies and governance structures of these cities, comparing the extent to which national and municipal governments could implement measures aimed at building climate resilience at the urban scale.

Fossil fuel-led growth has been a major contributory factor to rapid rise in carbon emissions. Emissions of CO_2 from fossil fuel combustion and industrial processes contributed about 78 per cent of the total GHG emissions increase from 1970 to 2010 (IPCC, 2014a). Cutting down on use of fossil fuels and shifting to clean energy sources is therefore a major strategy for combating global warming. Chapter 12 by Timmons discusses the economic principles that should govern renewable energy choices. Renewable energy sources including biomass energy, water power, wind, solar power and geothermal energy have somewhat different characteristics from fossil fuels: they are capital intensive, with their costs dependent on interest rates; their costs are highly dependent on their scales and production sites; and many renewable energy sources are available only intermittently. Minimizing total cost of providing renewable energy suggests that marginal costs of individual renewable energy sources be equal. In many areas, use of more expensive sources such as solar photovoltaic energy will thus make it economical to develop hydropower and wind power on sites that might not appear feasible currently. Similarly, the marginal cost of renewable energy suggests that additional energy conservation will be economical, and a large portion of the transition to renewable energy will likely be accomplished through energy conservation rather than energy production. To minimize total costs, equality of marginal costs must also hold at all points of time and from all points in space, suggesting possibilities for energy storage and long-distance energy transmission facilities. While the market would eventually accomplish a renewable energy transition owing to rising fossil fuel prices, public policy will likely be needed to make the renewable energy transition soon enough to avoid the worst effects of climate change.

Part III: Incentives, Governance and Policy

Building climate resilience requires an enabling environment in terms of appropriate incentives, governance, institutions and policies. These issues are examined in the chapters included in Part III.

Over the past 25 years, a growing number of countries have adopted policies that place a price on the emissions of carbon dioxide (CO_2) and other GHGs. Regardless of whether such carbon pricing is implemented through taxes or emissions trading schemes (ETS), these policies can raise substantial amounts of public funds. How should the revenues raised by carbon pricing policies be managed? Chapter 13 by Barrage surveys both the economic models and the policy approaches that have been used to address this question from the perspectives of economic efficiency, equity and political feasibility. First, from an efficiency-maximizing perspective, public finance models typically find that capital income tax reductions would be the optimal use of carbon revenues. Recycling the revenues through labour income tax cuts ranks second, whereas rebating the revenues directly to households as lump-sum payments entails the largest efficiency costs. In contrast, based on equity considerations, lump-sum rebates can be preferable to labour tax reductions in addressing the regressivity of carbon prices. In contrast, an ETS with free permits and corporate income tax cuts is likely the most regressive option, but would compensate industries and thus achieve political feasibility at the lowest cost.

Reducing emissions from deforestation and forest degradation (REDD+) is a recent global response to the challenges posed by emissions from deforestation and forest degradation. Global interest in REDD+ is growing and warrants a comprehensive review of what REDD+ is, how it is implemented and what key issues need to be considered to steer REDD+ towards a climate resilient socio-ecological system. Chapter 14 by Mohammed and Inoue indicates that REDD+ can be understood as global multilevel forest governance that links different actors at different scales, from local to global (glocal). REDD+ has evolved from the narrowly scoped reducing emissions from deforestation (RED) to the current REDD+, which has considered not only deforestation but also forest degradation, sustainable forest management, and social and biodiversity safeguards through repeated engagement and negotiation among glocal actors since the 2005 Cancun IPCC meeting. Currently, a total of eight actors, ranging from multilateral financial institutions to national governments and indigenous people, are identified as playing an important role in the negotiation and/or design and/or implementation of REDD+. The authors identify five salient issues that need to be addressed to achieve a resilient socio-ecological system. These are: lack of a strong global institution; biodiversity concerns; lack of competitiveness; lack of tenure clarity; and prospects for distributive and procedural injustice.

Giving favoured access to climate finance and clean technologies is critical to enabling developing countries to transit to a low carbon economy and society. Global climate finance to developing countries is set to rise with the establishment of the Green Climate Fund. To be effective, climate finance must reach and be prioritized by the communities that need it most and be used to fund solutions that work on the ground. To achieve this, mechanisms need to be put in place to channel the money from national level to local communities in a way that is transparent, participatory and efficient. The institutional architecture of existing devolved or decentralized government provides a ready-made framework which offers good value for money and will be sustainable as finance flows increase in the future. Orindi et al.'s analysis (Chapter 15) of the Adaptation Consortium in Kenya indicates that devolved County Climate Change Funds are proving to be an effective mechanism to deliver climate finance in support of community-prioritized investments in public goods that build local resilience to climate change.

The European Union (EU) has a consolidated climate and energy policy, which has played a pioneering role by adopting a wide range of emission reduction measures. However, it is often claimed that these measures have a negative effect on the economy, especially in terms of growth and competitiveness. Chapter 16 by Carraro and Davide reviews the recent literature on the European experience to understand if these concerns are true. Their analysis primarily focuses on studies assessing major economic indicators, such as costs, competitiveness, carbon leakage and income distribution, with the objective of highlighting both the limits and the opportunities of the EU's regulatory framework, as well as its potential for reconciliation with socio-economic objectives.

The atmosphere is a community asset that belongs to all people. The problem is that it is treated as an open access resource: anyone can emit carbon dioxide into the atmosphere with no consequences to themselves but huge cumulative consequences to the climate and the global community. Many agree that charging companies and individuals for the damages their emissions cause, for example a comprehensive carbon tax or cap/auction/dividend/trade system, would drastically cut emissions. However, despite some interesting regional experiments, implementing this kind of system via international negotiations at the global scale has proven close to impossible. A few critical governments, influenced too much by fossil fuel interests, have been blocking binding commitments and effective economic instruments. In Chapter 17, Costanza argues that global civil society can change this if it *claims property rights* over the atmosphere. By asserting that all people collectively own the sky, legal institutions surrounding property can be used to protect our collective rights, charge for damages to the asset and provide rewards for improving the asset. This idea has been proposed by Peter Barnes and others. The public trust doctrine is a powerful emerging legal principle that supports this idea. The doctrine holds that certain natural resources are to be held in trust as assets to serve the public good. It is the government's responsibility as trustee to protect these assets from harm and maintain them for the public's use. Under this doctrine, the government cannot give away or sell off these public assets to private parties. The public trust doctrine has been used in many countries in the past to protect water bodies, shorelines, fresh water, wildlife and other resources.

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