Chapter 2
Climate Change: Impacts, Uncertainties and Adaptation

Climate scientists are becoming increasingly certain of the drivers and impacts of global climate change, while models for projecting future climate change are progressively improving. Nevertheless, significant uncertainties inevitably remain and there is a lack of robust data on the regional level. Small islands, on the one hand, are often represented as drowning lands and climate change's first victims due to sea-level rise. On the other hand, detailed data about the impacts of climate change are hardly available for small islands. Individually they have little power to deal with long-term adaptation by themselves.

The findings of climate science provide sufficient evidence to show that mitigation measures alone—efforts to keep emissions levels and thus global warming below a certain level—are not enough. Attentions should be turned towards adaptation—adaptation in circumstances of uncertainty. Adaptation to climate change is not only a question of political strategies and technological solutions, but it is also a social challenge. It is important to look at the regional and local level of communities and to understand potentials and obstacles of societal action as well as the necessity and circumstances of adaptation measures. This is where social sciences and integrative, interdisciplinary research play a major role.

Therefore, in addition to an overview of current insights in climate sciences, I also provide an overview of sea-level rise, not least of all because it will probably be the 'most immediate, most certain, the most widespread, and the most economically visible' (Pilkey and Young 2009: 4) impact of climate change. In addition, a focused account of the implications of the 'greatest potential threat' (Byrne and Inniss 2002: 10) to small islands will be given in Sect. 3.3.1.

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2.1 Observations and Projections

According to the IPCC '[h]uman influence on the climate system is clear' (IPCC 2013: 1); the causes of changes in mean air temperatures are 'extremely likely' (IPCC 2013: 5) to be linked with anthropogenic influences on the composition of the earth's atmosphere since the beginning of the industrial era. Greenhouse gas emissions can be attributed mainly to countries from the so-called global north (Victor et al. 2014: 113). Mean surface temperatures, widely viewed as an indicator of climate change, show an increase of 0.85 °C between 1880 and 2012 (Stocker et al. 2013: 37). Warming oceans and melting glaciers and ice sheets have already caused a rise in the global mean sea level of 0.19 m between 1901 and 2010 (Stocker et al. 2013: 46). Further observations of climate change impacts include ocean acidification and warming of oceanic water masses, leading to coral bleaching and changing patterns of fish stocks. Similarly, changing atmospheric temperatures and precipitation patterns influence the composition of flora and fauna, causing shifts in climatic zones. An increase of extreme weather events, such as droughts and tropical cyclones, is often linked with climate change, too. Observations show such increases, but the causes are still not completely established and trends differ greatly by region (Stocker et al. 2013: 50).

Based on so-called general circulation models (GCM), climate scientists develop projections for possible futures under climate change. Such models help us to better understand the physics of the climate system and deduce future developments. The earth's climate system is understood as a complex system. As such, climate change models can only have limited predicting power due to unknown thresholds, abrupt changes and features of chaos. Accepting these limitations of climate models 'does not negate their value in informing society about possible futures. However, it does suggest that these models may not be preparing us for some possible responses' (Harrison and Stainforth 2009: 111). The improvement of climate models has also helped to define the existing uncertainties. The question is how we deal with uncertainties. To allow for effective political action, it must be clear that '[w]e do not need to demand impossible levels of certainty from the models to envisage a better safer future' (Maslin 2013: 270).

The main impacts expected of a further rise in global mean surface temperatures (Fig. 2.1) are increased extreme temperatures, further ocean acidification and a rise in global mean sea level of almost one metre (depending on the model) until the end of the twenty-first century (IPCC 2013: 10–13).

2.2 Sea-Level Rise

It 'is *virtually certain*' (Stocker et al. 2013: 100, emphasis in original) that sea-level rise will continue 'for centuries to millennia' due to the inertia of the climate system and the ongoing thermal expansion of the oceans, irrespective of mitigation targets

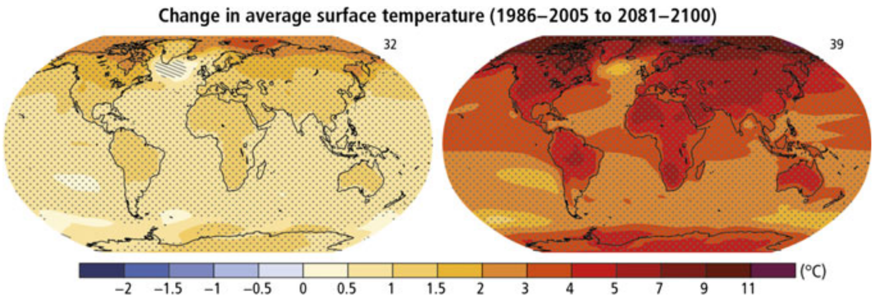

Fig. 2.1 Projected change in average surface temperatures between 1986–2005 and 2081–2100 (*left* RCP2.6, *right* RCP8.5) (*Source* IPCC 2014: 61)

set by the international community. Mitigation of greenhouse gas emissions is nonetheless important in preventing further long-term climate change. A warming of mean surface temperature by 2–4 °C compared to pre-industrial levels might even cause thresholds to be surpassed, threatening irreversible changes to global circulations and climate systems, because '[t]he long-tailed uncertainty implies that there is a considerable risk that relative sea level rise will exceed recent high-end scenarios' (Grinsted et al. 2015: 21). Such thresholds could imply a complete melting of the Greenland or West Antarctic ice shields and consequently cause a sea-level rise of up to 3–7 m (cf. Schaeffer et al. 2012, Stocker et al. 2013: 100).

To understand the implications of sea-level rise, it is important to distinguish between eustatic and isostatic sea level changes. The former results from a changing volume of water masses or accommodation space in oceans due to tectonic plate movement. The latter is caused by relative sea level falls due to rising land as the result of glacial melting (Pilkey and Young 2009: 23). Factors such as surface winds, freshwater influx, water temperature and ocean currents influence relative sea levels. Thus, changes in sea level are not evenly distributed across the planet: 'regional sea level changes may differ substantially from a global average' (Church et al. 2013: 1191). Moreover, sea-level rise due to thermal expansion is a linear event, in contrast to sea level-rise resulting from melting ice sheets (Pilkey and Young 2009: 65). Projections show that sea-level rise can be expected in most regions across the oceans, except regions near glaciers and ice sheets, where a sea-level fall is projected. The highest regional deviations above the global mean are projected to be in the South Pacific and South Atlantic, as well as around North America. Near the Arctic and Antarctica, projected sea level changes lie as little as fifty per cent below the global mean (Fig. 2.2).

In addition to the uncertainties and inaccuracies of modelling and regional downscaling of sea-level rise projections, the actual impact of sea level changes on coasts differs from place to place. Vulnerability to sea-level rise does not only depend on the magnitude of climate-induced increases in sea level. Geomorphologic and non-climate coastal drivers influence how coastlines adapt to changes in sea level. The impacts of sea-level rise will especially affect

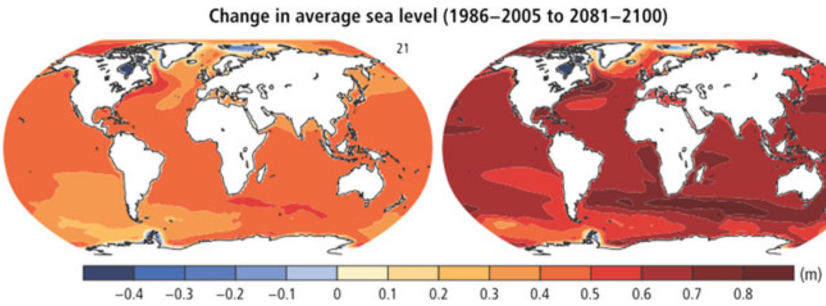

Fig. 2.2 Projected change in average sea level between 1986–2005 and 2081–2100 (*left* RCP2.6, *right* RCP8.5) (*Source* IPCC 2014: 61)

low-elevation coastal zones, such as deltas, which are often also densely populated (e.g., in South, Southeast, and East Asia). Moreover, small and low-lying islands, such as those found in the Caribbean, and Indian and Pacific Oceans, are among the most affected regions (Nicholls and Cazenave 2010: 1519).

2.3 Adaptation

Apart from climatic changes and other natural pressures on coastal ecosystems, however, a decisive factor on how coasts adapt to sea-level rise is human action—something that is not included in climate models. Many problems associated with sea-level rise are in reality problems caused by human action, such as removal of coastal vegetation, sand mining or maladaptation involving seawalls. Mangroves are used as materials for the construction of houses and boats; wetlands are cleared for aquacultures; beaches are built up for tourism infrastructure (cf. Pilkey and Young 2009: 108). On the other hand, the vulnerability of coastal zones also depends on non-climate and non-natural factors, such as population density and existing adaptive capacity, which includes many factors (see below). Seen from this perspective, small islands are the most vulnerable regions to sea-level rise (Barnett and Adger 2003). A major problem of the IPCC projections for coastal management is that they focus on changing mean sea levels rather than peak tides and major flood events, which are most relevant to coastal communities (Hinkel et al. 2015: 188).

Despite uncertainties, and because of regional differences regarding the impacts of climate change, adaptation planning is the main task of climate scientists, next to physically understanding and modelling climatic changes, since '[a]n improved understanding of adaptation is fundamental, because it is one of the biggest determinants of actual rather than potential impacts' (Nicholls and Cazenave 2010: 1519). The IPCC defines adaptation as '[t]he process of adjustment to actual or expected climate and its effects' (Noble et al. 2014: 838). However, the 'diversity of local conditions is one crucial barrier to adaptation' (Eisenack 2012: 108). Therefore, effective adaptation relies on the assessment of adaptation needs, which in turn requires information on risks and vulnerability for the biosphere, society, institutions and the private sector, as well as identifying technological and financial capacities. This assessment is multi-dimensional and multi-scalar, considering the regional, national and international levels, and is the basis for the development and choice of adequate adaptation pathways (Noble et al. 2014: 839–844).

Two major categories of adaptation to climate change impacts are technological/structural and management/socio-political measures (Nunn 2009; Noble et al. 2014). Nunn (2009) identifies technological/structural measures such as the restoration of ecosystems (e.g., mangrove forests), changing agricultural crops in response to temperature variability, infrastructure improvement, protection and relocation in response to increased storm surges, natural conservation of ecosystems, relocation of settlement and coastal protection in response to sea-level rise. Management/socio-political imperatives, on the other hand, include national strategy plans and long-term planning, hazard mapping, agricultural management, sponsorship of research, legislation regarding construction and marine protected areas (Nunn 2009: 222; cf. Petzold and Ratter 2015).

The range of adaptation options, however, is much wider than the few examples given above. The purpose of assessing the adaptation needs of a certain place is to identify effective solutions. The variation in responses to sea-level rise exemplifies how certain adaptation options that are realistic in one region will not work in others (e.g., the Netherlands, unlike Bangladesh, has hundreds of years of experience with dyking, technical knowledge, financial resources and necessary infrastructure to implement solutions, including dykes, building codes, warning systems and shelters against sea-level rise). In poor countries, responses to sea-level rise are often more effective since the more radical solution (i.e., usually location) is chosen, whereas rich countries tend to prefer costly but short-term solutions, such as raising seawalls and dykes (Pilkey and Young 2009: 168).

Moreover, adaptation needs must be identified so that maladaptation can be avoided. According to the IPCC 'maladaptation refers to actions, or inaction that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future' (Noble et al. 2014: 857). Examples of maladaptation are the construction of hard infrastructures, such as seawalls, while neglecting negative long-term impacts, whether on the ecosystem or on social structures. Maladaptation can also be caused by taking action too late or too early due to lack of information, or by applying traditional solutions that are no longer sufficient (Noble et al. 2014: 858). Protective measures against sea-level rise, such as seawalls or artificial beaches created by sand nourishment, also generate a sense of security and encourage construction, which can have negative impacts that were unforeseen when the adaptation measure was planned (Pilkey and Young 2009: 166). Copying successful adaptation measures from one region to another can also lead to unnecessary environmental damages if they are not adjusted to local circumstances (Pilkey and Young 2009: 135–136).

2.4 Community-Based Adaptation

According to Adger et al. (2013: 112), after National Research Council (2010) research and policy on adaptation and mitigation have problematically 'largely focused on the material aspects of climate change, including risks to lives and livelihoods, the costs of decarbonising economies and the costs of impacts on various sectors of the economy'. Adaptation, however, is always culturally and socially framed. Within this context, I concentrate on social features, which can constrain but also enhance adaptation options. As the large body of vulnerability literature shows, social contexts influence perception of risks, preference of adaptation option and actors involved (Blaikie 1994; Cutter 1996; Adger 2006). Social structures, distribution of poverty and education also influence the degree of vulnerability and adaptive capacity of different members of a community. Moreover, sense of place affects how people accept certain adaptation options, including migration (Klein et al. 2014: 915–916). Certain features of social structures can also be advantageous in promoting adaptation measures, including distribution of local expertise, willingness within the community to commit to collective action, and high levels of trust and reciprocal help (cf. Petzold and Ratter 2015). Because of the inherent limitations of sea-level rise projections, vulnerable communities must live with a degree of uncertainty and accept expert qualitative estimates (Pilkey and Young 2009: 58; Barnett and O'Neill 2010). Decision-makers and planners can benefit from integrating community resources into socially, ecologically and financially sustainable solutions for dealing with changes to coastal habitats. Effective solutions translate local knowledge and collective action into local adaptation measures, while raising acceptance and supporting communities in the implementation of adaptation measures (cf. Mercer et al. 2012; Jones and Clark 2013).

Community-based adaptation (CBA) is an approach that combines adaptation and development while benefiting from local resources and ensuring effective implementation and outcomes of adaptation measures. CBA 'addresses the locally and contextually specified nature of climate change vulnerability' and stresses the role of 'participatory processes, involving local stakeholders and development and disaster risk reduction practitioners, rather than being restricted to impacts-based scientific inputs alone' (Ayers and Forsyth 2009: 26). Such community-based approaches are often developed by local or international non-governmental organisations (NGO) in cooperation with local communities by holding consultation meetings, conducting household surveys and developing tools and technologies for adaptation measures that can be implemented by the community itself. Examples are floating gardens and the construction of elevated houses in flood-prone areas, or the establishment of sharing networks (e.g., for food, tools, and skills) in isolated communities (Ayers and Forsyth 2009; Dodman and Mitlin 2013). Difficulties associated with CBA can be problems of governance and relations of power that constrain such bottom-up initiatives (Dodman and Mitlin 2013). Moreover, there is often a lack of data regarding future impacts of climate change, which makes it difficult to distinguish between community-based development and adaptation. It is also difficult to monitor and learn from, or ‘upscale’, CBA projects due to their place-specific character. Last but not least, these projects might not suffice for long-term climate change if emission levels continue to rise (Ayers and Forsyth 2009: 28–29).

Social sciences contribute to the analysis of potentials and limitations of adaptation options, by identifying driving factors and obstacles in a regional context. This can help in implementing adaptation measures in an effective and socially sound way. Social science methods can produce essential insights that complement the data gained from climate change models, projections and quantified vulnerability assessments.

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