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Adapting to Climate Change: Methods and Tools for Climate Risk Management

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Adapting to Climate Change: Methods and Tools for Climate Risk Management

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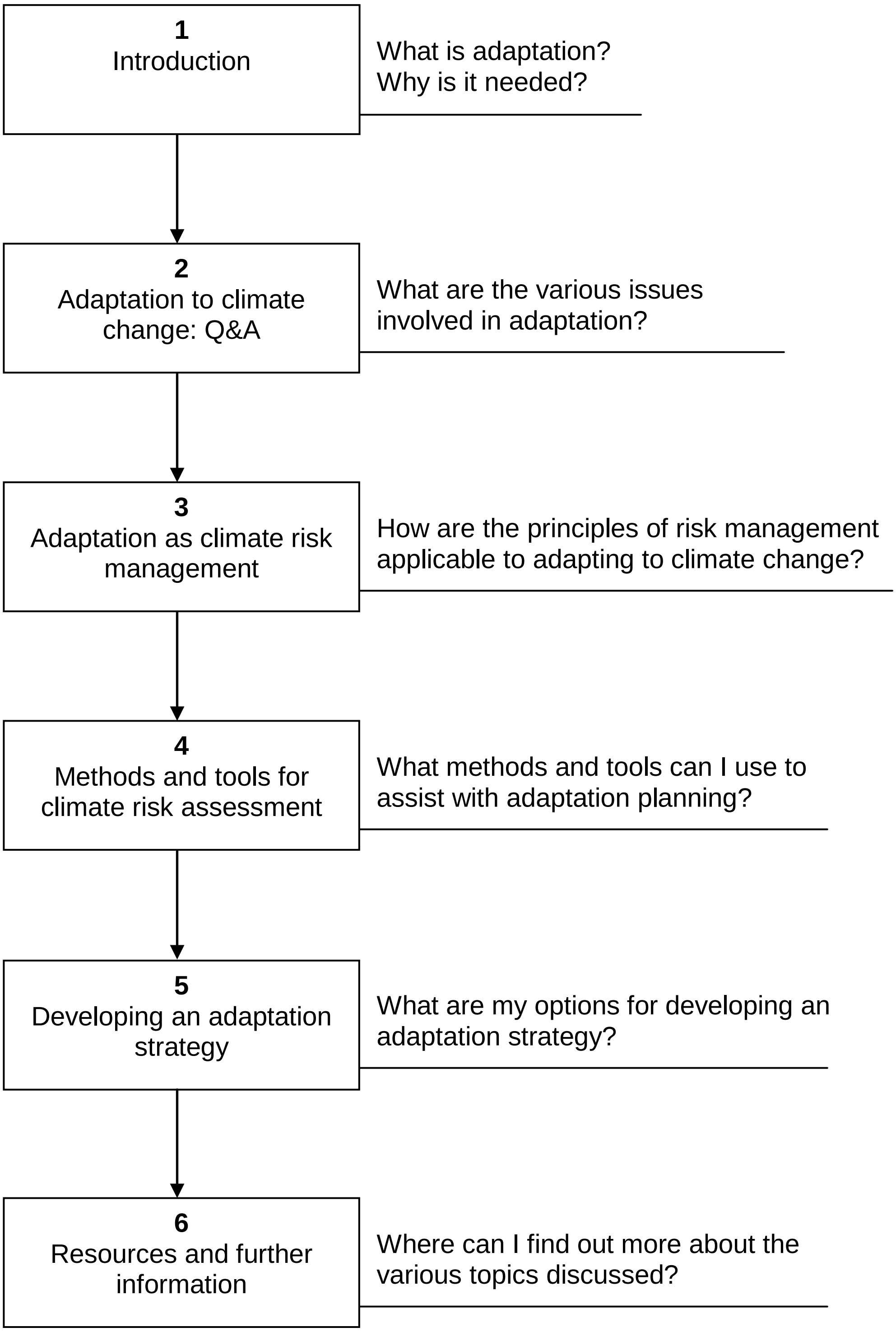
Preface

Anthropogenic climate change, and the risks that a changing climate presents, is now widely acknowledged to be a reality, and one that represents a serious threat to organisations in the private and public sector, as well as to society as a whole. These risks range from adverse impacts on ecosystems and biodiversity, water resources, food production, and infrastructure. As the Earth continues to warm, these risks are likely to increase in relevance, and as such organisations that have business areas which are sensitive to climate related risks, will need to adapt to this changing environment, in order to reduce or avoid any negative consequences, and seize any positive consequences.

Adaptation to the risks posed by climate change and variability is a complex process, and one that is still relatively new to many organisations. To date, progress on adaptation in both the private and public sector has at best been patchy. In view of the relative novelty of the issue, together with the complexity of the challenge, there is a clear need for guidance and support, to help assist organisations in making progress with adaptation.

This guidebook, *Adapting to climate change: methods and tools for climate risk management*, seeks to provide organisations with the information they need in order to understand the range of issues involved in adaptation, and to help them make informed decisions about how they may make progress with adaptation planning in practice. This version of the guidebook is a first order draft, to which feedback is warmly welcomed. Feedback comments should be sent to the main author at this email address paul.bowyer@hzg.de.

Chapter Routefinder



Executive Summary

Key Messages

- Climate change, and the impacts of climate change and variability, are real and already have major consequences on a range of different business activities, which are of relevance to organisations in both the public and private sector. As the world continues to warm, these impacts are likely to increase in relevance.
- Adapting to the impacts of climate change and variability, to reduce any negative consequences, and seize any positive consequences, is an issue of forward planning, and is an urgent requirement.
- Adaptation to climate change is a complex process, requiring the synthesis and integration of a range of different approaches, methods, tools, and stakeholder engagement.
- A risk management framework is highly attractive for dealing with adaptation, and the consequences from climate risks.
- The potential for effective climate risk management, and thus adaptation, is increased by considering all the relevant climate and non-climate factors that relate to a particular adaptation problem, and by integrating climate risks into corporate risk management strategies.

Anthropogenic climate change, and the risks that a changing climate presents, is now widely acknowledged to be a reality, and one that represents a serious threat to society as a whole. These risks include impacts on ecosystems and biodiversity, water resources, food production, and infrastructure, which are of relevance to a range of different organisations in the private and public sector. Adapting to these climate risks is essentially an issue of climate risk management, whereby an organisation seeks to minimise any potential negative consequences (threats), and make the most of any positive consequences (opportunities). Adaptation to the risks posed by climate change and variability is a complex process.

While the risks posed by climate change are well recognised, and some organisations are making progress with adaptation, overall, progress in both the public and private sector has, to date, been generally rather sluggish.

This guidebook, *Adapting to climate change: methods and tools for climate risk management*, seeks to provide organisations with the information they need in order to understand the range of issues involved in adaptation, and to help them make informed decisions about how they may make progress with adaptation planning in practice. The focus of the guidebook is on describing a range of methods and tools that can be applied when carrying out a climate risk and adaptation assessment, and associated issues with their application, chief among which is the issue of uncertainty in adaptation decision making. As such, the guidebook is most useful in relation to raising awareness of the need for adaptation, and in establishing an evidence base of decision-relevant information to help inform the development of strategies and actions in the adaptation planning process.

Climate change, climate impacts and the need for adaptation

The Inter-governmental Panel on Climate Change (IPCC) in their fifth assessment report, stated that warming of the climate system was now "*unequivocal*" (IPCC 2013). Over the period 1880-2012 the global average surface temperature of the Earth has warmed by 0.85^{o}C (IPCC 2013), and this trend in global average surface temperature is shown in figure A. Figure A also shows that while there is yearly variation, when taking the decadal average, it is shown that the last three decades have been successively warmer than any preceding decade since 1850. Figure A also shows that this increase in surface temperature is statistically significant over most areas of the Earth's land surface. Projections from global climate models indicate that the Earth will continue to warm over the 21st century, with an increase of 0.3^{o}C to 4.8^{o}C projected by the period 2081-2100, the range being dependent on how future society develops.

Changes in climate will have a range of different impacts in various economic sectors. Using the example of changes in global average surface temperature, figure B outlines some possible impacts that may be expected at various levels of global surface warming. Clearly the more the Earth's surface warms, the larger and more serious the impacts will be. This serves to highlight the dual response to climate change that is needed, mitigation to avoid the more serious or dramatic impacts, while adaptation is needed to be able to cope with the changes that we are already committed to.

For an organisation, the impacts from a changing climate may present new risks and/or make managing existing risks more challenging. These impacts may be observed in various areas of an organisation's business activities, including in processes, finance, logistics, and markets. Another aspect of adapting to climate change is that it may not just be those changes in local conditions that are of concern or need consideration, but also, in an increasingly interconnected globalised world, changes in other parts of the world, where, for example, a German manufacturer sources components. The disruption caused to global supply chains by flooding in Thailand in 2011, serves as a key illustration of this point.

Making the case for adaptation

Clearly, the climate has changed and will continue to change over the 21st century. Under climate change, an organisation that has business areas which are sensitive to changes in climate, may be more susceptible to climate risks in the future. There are a number of reasons why it makes good sense to start thinking about and making progress with adaptation to climate change. These include:

1. **Climate non-stationarity**. Many existing management strategies, regulations and standards in a range of activities from water resources management to building regulations, have operated under the assumption that the climate was well known and varied within a certain well defined range, based on past observations and experience. This is what is referred to as climate non-stationarity (Milly *et al*. 2008). Under climate change, this assumption is no longer valid. As such, climate non-

stationarity may represent the end of business-as-usual. Consequently, existing management strategies may need updating in the light of this new knowledge, or at the very least, should be tested to see how they may perform in the future, under a changed climate.

2. **Co-benefits with existing business objectives**. Adaptation may sometimes be seen as thinking about climate change that may happen a long time in the future, and as such, can often be deemed to be low priority, compared to other factors in the business environment, and thus not acted upon. However, starting a process of thinking about how an organisation may be impacted by a changing climate, and considering future risks, may lead to the identification of strategies or ideas which can have immediate benefits to an organisation today, as well as ensuring that future activities are more resilient in the face of change.
3. **A business opportunity and ensuring future viability**. While the focus of the discussion on climate change typically centres around the threat that it poses, and thus the seriousness of the problem, this doesn't mean that there won't be opportunities. Indeed, if we are to be able to adapt then this will require effective solutions – products and services – from both the public and private sector. It is general good business practice to be aware of emerging opportunities for business development, and climate change is a major driver of change in the business environment, and this can lead to opportunities, but may also lead to changes in the regulatory environment which an organisation may need to respond to.
4. **Cost effective**. It is often more cost effective to deal with any business threats as they arise, rather than allowing them to develop into bigger problems. The cost of action after the event, or when changes become clearly evident is typically achieved at much greater cost, than acting ahead of time.
5. **Competitive advantage**. Being an early mover in any kind of market (private or public), can ensure that you are ahead of the game in terms of product or policy development, and well placed to seize opportunities as they arise, and reduce or avoid any potential threats.
6. **Reputation and image**. Being seen to be in tune with, and responding to the issues of the day can be good for your image, especially if you operate in an environment where such issues are important, in terms of stakeholder relations, and consumer and public perception. Moreover, it can also improve your perception as being a good employer, helping to attract and retain good staff.
7. **Investor sentiment**. Being active in relation to climate change and the various risks it may pose to your organisation, is an issue that is of increasing relevance to securing financial investment. As the general awareness of climate change within society increases, investors are becoming more demanding of organisations, and increasingly want to see climate risks disclosed and reported in an organisation's risk profile.

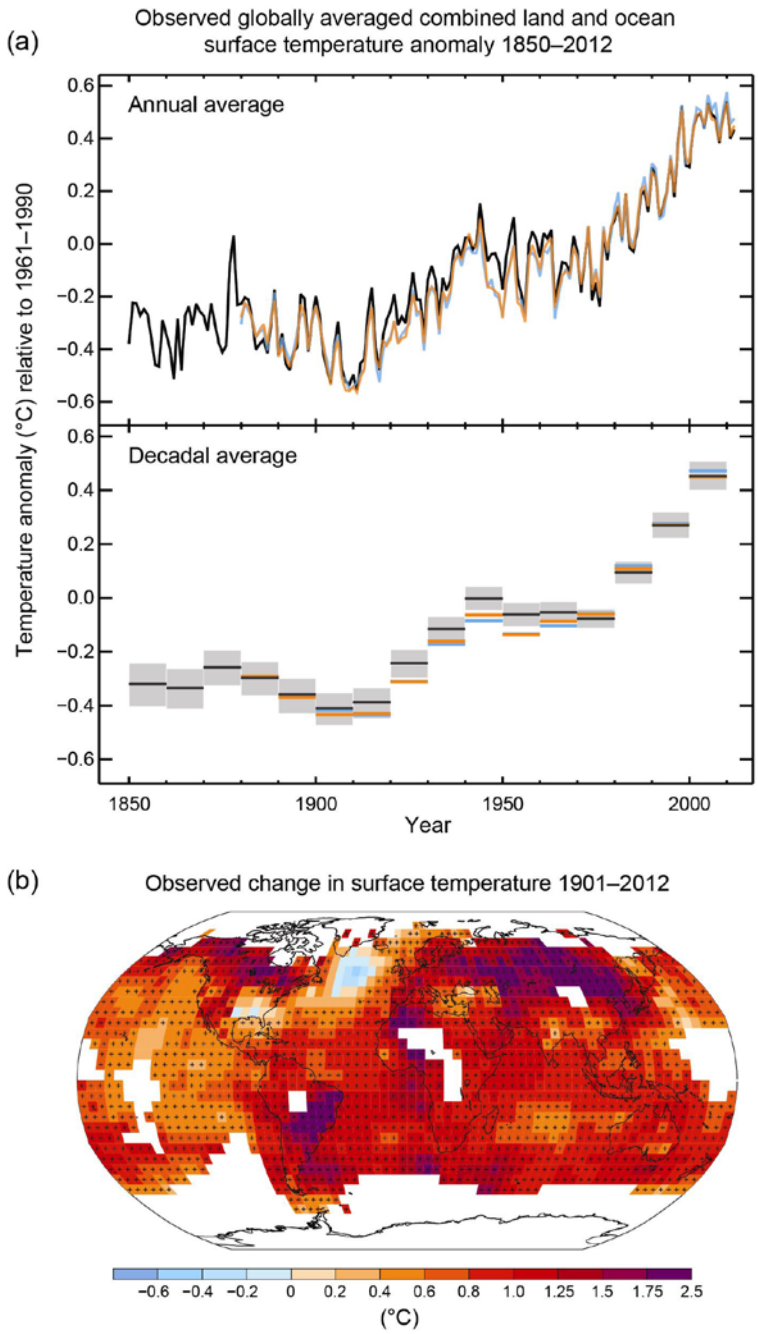


Figure A. (a) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 1961−1990. (b) Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset (orange line in panel a). Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign. *Source*: IPCC (2013).

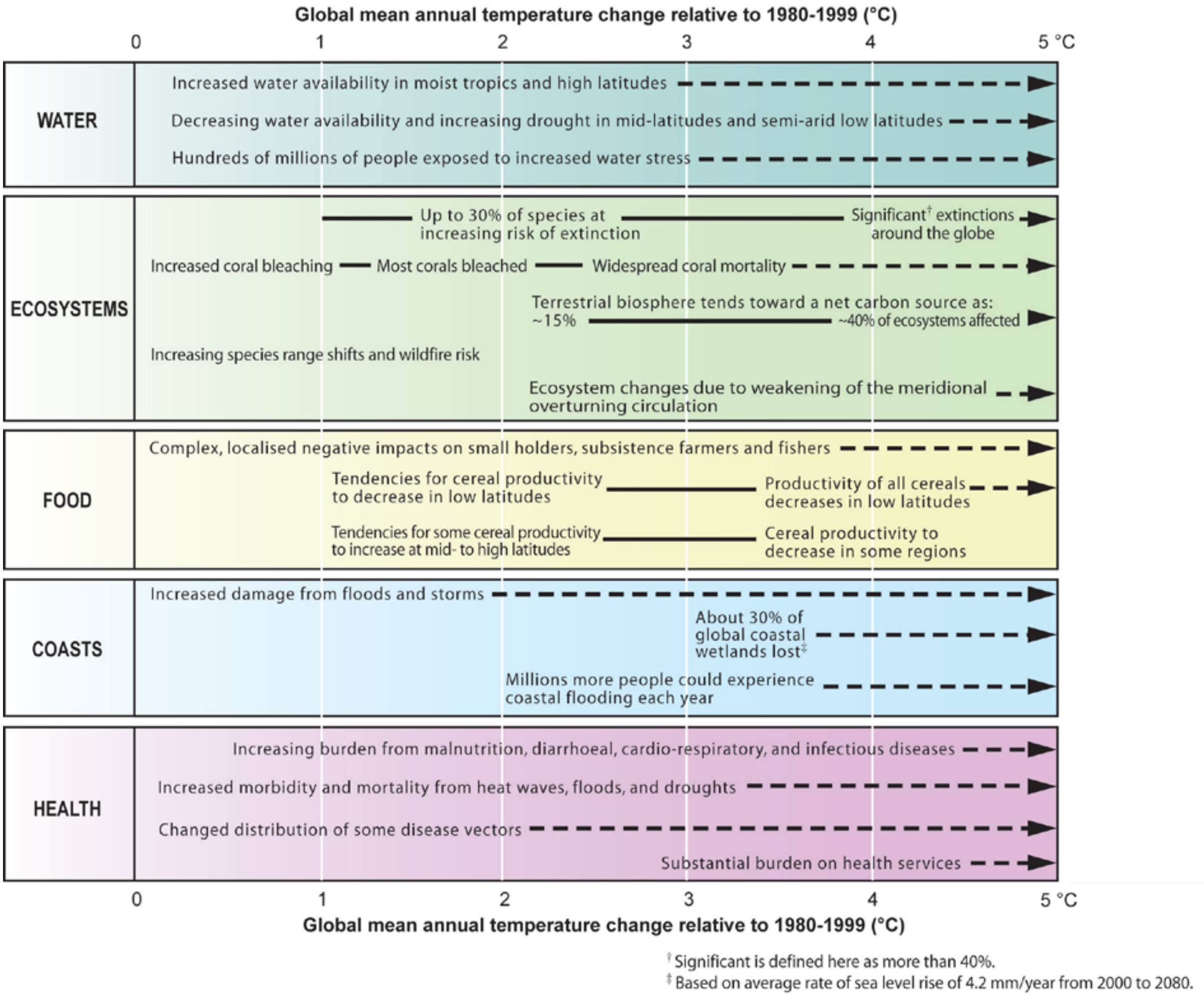


Figure B. *Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts, dotted arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of the text indicates the approximate onset of a given impact. Quantitative entries for water stress and flooding represent the additional impacts of climate change relative to the conditions projected across the range of Special Report on Emissions Scenarios (SRES) scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. All entries are from published studies recorded in the chapters of the Assessment. Confidence levels for all statements are high. Source*: IPCC (2007c).

Adaptation as climate risk management

This guidebook frames adaptation to climate change as an issue of climate risk management. We adopt the ISO 31000:2009 definition of risk, as being: "The effect of uncertainty on business objectives", and risk is calculated as the product of the likelihood of a climate-related event, and the consequences. Risk can have both negative and positive consequences, which in this guidebook are referred to as threats and opportunities, respectively. All organisations, be they in the public or private sector, will have business plans and objectives, some of which may be affected by, or sensitive to climate impacts. Business objectives are taken to mean the values, goals, and targets that any organisation may have or desire to obtain. These objectives can be analysed as to the effect that climate and other relevant factors e.g. socio-economic and socio-political, may have on their successful achievement.

A risk management framework provides a means within which to systematically analyse these risks, understand how they are generated as a result of the interaction of climate and non-climate factors, what the negative and positive consequences may be, and how we may be able to intervene to reduce threats and make the most of any opportunities. The risk management framework as applied to adaptation is shown schematically in figure C. Stages 3 and 5 of this process is where the main focus of this guidebook is placed.

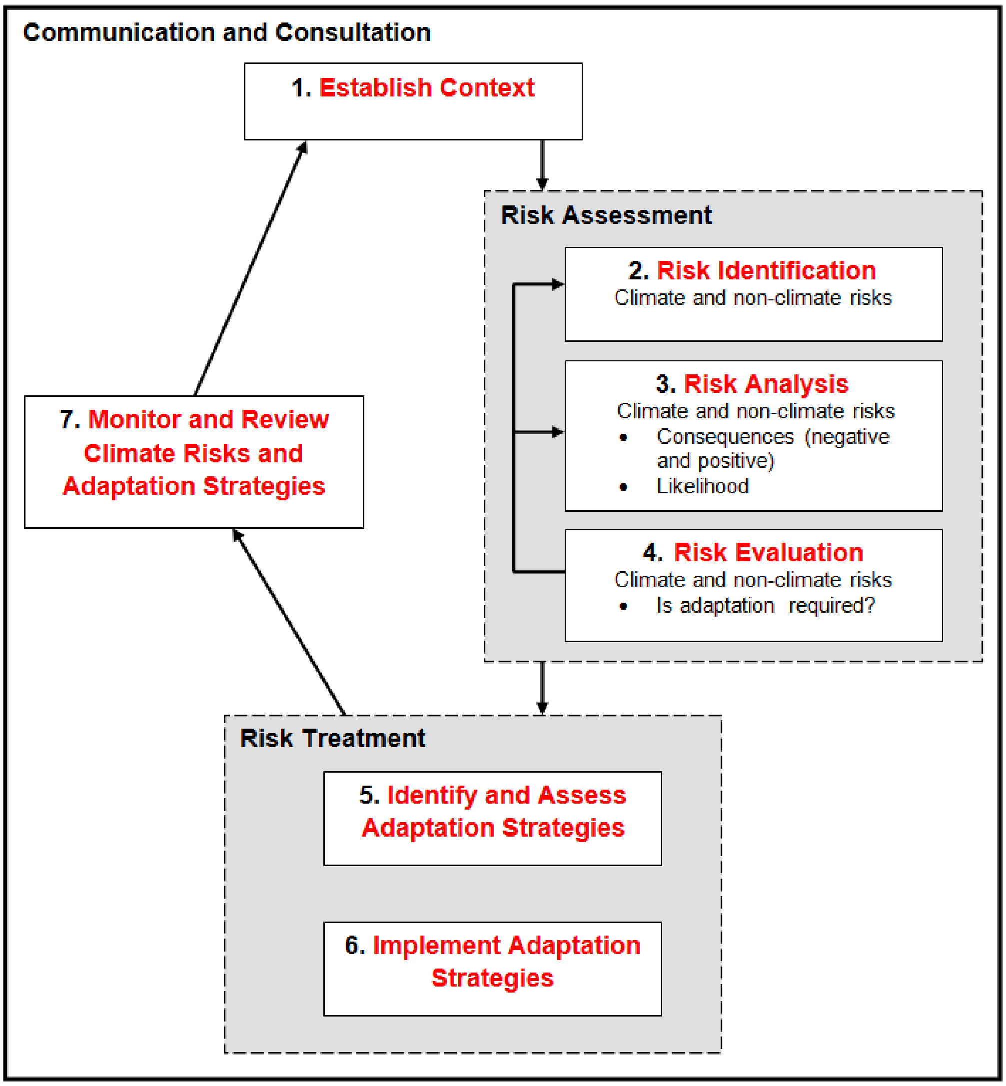


Figure C. A schematic of adaptation as a process of risk management, showing the various stages involved in the risk management process and their interactions, as applied to climate change adaptation. The risk management process may not proceed in a linear process from step 1 through 7, and in practice steps 3 and 5 may be performed in combination. *Source*: Adapted from ISO 31000:2009.

Assessing climate risks and adaptation options

Increasing the chances for successful adaptation requires a sound understanding of how a given system functions, in response to the key driving variables (climate and non-climate), which may generate a risk for an organisation. This system understanding needs to be represented in the form of a causal model which establishes the relationships and inter-relationships between these variables, and how risks are generated, and thus how we may intervene with well-chosen adaptation actions to minimise threats and maximise opportunities.

These causal models can be relatively simple qualitative conceptual models, to highly complex quantitative numerical models. A conceptual model is a framework or representation of the causal relationships between the various factors that generate risk. Figure D shows an example of a conceptual model. Quantitative numerical models also use these causal relationships but represent the processes and relationships in numerical terms.

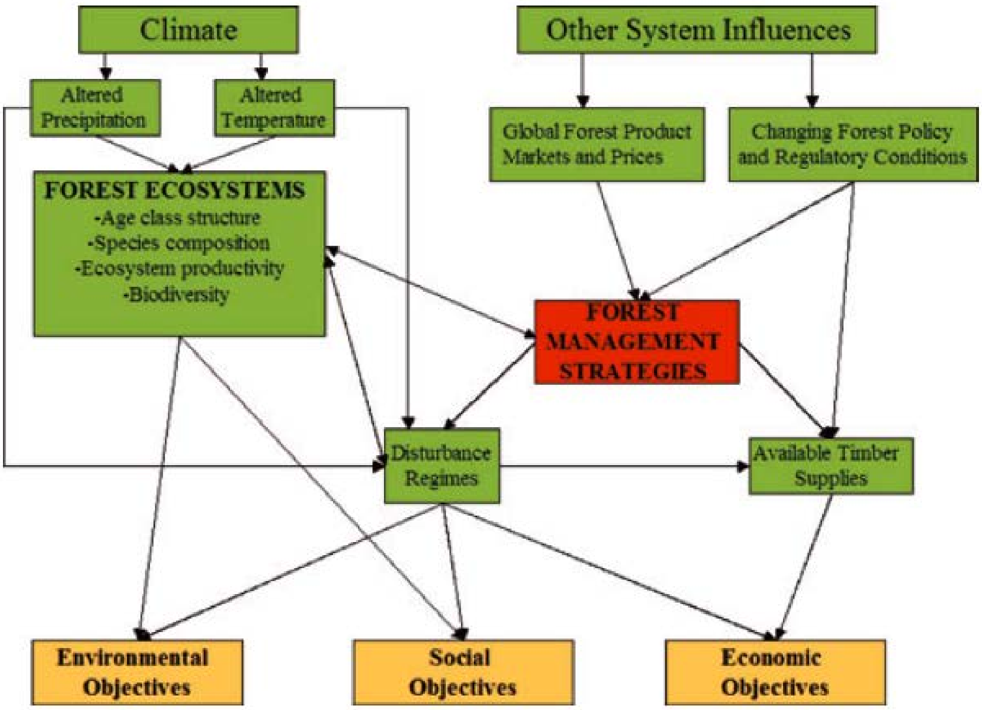


Figure D. An example of a conceptual model, as developed in relation to understanding the impacts of climate change on forest management. *Source*: McDaniels *et al*. (2012).

There will be many adaptation problems and issues that are so complex and data poor, that it may not be possible to develop a numerical model of the way in which risk is generated for a given system. As such, a qualitative conceptual approach is needed, and thus it is necessary to generate conceptual models whereby we think through the way in which possible changes in climate may impact a system, through brainstorming sessions, workshops, and logical reasoning. As such, learning and developing understanding of how a given system functions will rely on an organisation's collective experience and knowledge, and insights from employees. This information will play a crucial role in all climate risk assessments, and should not be viewed as containing little value, there is a lot of value in this, and any climate risk assessment – regardless of the range of applicable tools and methods – should be grounded in this kind of learning and context.

Using models to understand how a system functions does not however provide the answer or solution to adaptation problems. Rather, they provide information which may be used to inform a decision making process about which climate risks need treating - during the risk evaluation stage of risk assessment - and the effectiveness of various adaptation strategies, which may then be assessed against a range of criteria in the adaptation assessment stage of the risk management process.

About this guidebook

This guidebook is written for managers, analysts, and decision makers in the private and public sector. A range of different professionals may already be engaged in climate or environment related activities within their organisation e.g. on mitigation or sustainability issues, but for whom adaptation may be new, and something they wish to learn more about. This guidebook will also be informative for higher level decision and policymakers interested to learn more about the need for, and issues involved in adapting to climate change and variability.

This guidebook consists of six main chapters, and two appendices. **Chapter one** provides the background and relevant context for the guidebook. **Chapter two** provides a wide ranging discussion of the main issues of relevance to adaptation in a question and answer style. **Chapter three** presents a detailed discussion of the risk management framework as applied to adaptation. This chapter also discusses models and uncertainty, and the critical need for causal models in risk assessment. **Chapter four** provides a wide ranging discussion of a number of different methods and tools that may be used at the risk assessment and adaptation assessment stages of the risk management process. **Chapter five** provides a discussion of the ways in which adaptation strategies may be developed, methods, tools, and approaches that may be applied, and the implications of uncertainty when deliberating on adaptation decisions. **Chapter six** provides an annotated description and links to sources of further information for the main issues that are raised in each chapter. The two appendices deal with two topics in more detail. The development of the new representative concentration pathway climate scenarios are described in appendix 1, while appendix 2 provides two case studies of using a robust decision making framework, when assessing adaptation options.

1 Introduction

Chapter Highlights

- Explains the different ways in which we can respond to climate change, distinguishing between mitigation and adaptation.
- Makes the case as to why adaptation is necessary.
- Introduces adaptation as an issue of climate risk management.
- Outlines the purpose, aim and objectives and overall scope of the guidebook.

1.1 Responding to climate change

Global warming and anthropogenic climate change is now widely recognised as a reality, and responding to climate change is widely acknowledged as one of the greatest challenges facing society (UNFCCC 1992, World Bank 2012a, IPCC 2013). The Inter-governmental Panel on Climate Change (IPCC) in their fifth assessment report (AR5), stated that warming of the climate system was now "*unequivocal*", and that "*It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together.*" (IPCC 2013). Chief among these greenhouse gases is the accumulation of carbon dioxide in the Earth's atmosphere. Much international and national focus both at governmental level, and in the private sector, has been spent on developing policies and technologies to help reduce our carbon emissions, and transition to a low carbon economy (WBGU 2009, Ernst & Young 2010, CDP 2012, EU 2013a). Various national governments have targets to reduce carbon emissions by a certain percentage by a particular time period, for example, member nations of the European Union (EU), have a target of reducing emissions by 80-95% below 1990 emission levels by 2080. These efforts to reduce carbon emissions are termed climate mitigation. To date however, there has been very slow progress in reducing global carbon emissions (GCP 2012). Over time, this has helped bring the realisation that the climate will continue to change for the foreseeable future, and that in addition to striving to reduce our emissions, we will inevitably have to adapt to changes in climate that our past and continued emissions commit us to (Solomon *et al*. 2007). This has been a relatively recent recognition and consequently international and national efforts and policies in relation to climate change adaptation are less well developed, than those in mitigation. Nevertheless, action is starting to be taken both at governmental level and in the public and private sectors (DAS 2008, Agrawala *et al*. 2011, ICLEI 2013, EU 2013b).

Adaptation and mitigation are both urgently needed if we are to be able to respond to the projected impacts of climate change, and avoid some of the more extreme changes and impacts that may occur (World Bank 2012a). As such, adaptation and mitigation are complementary rather than competing objectives, and table 1.1 compares and contrasts the various characteristics of adaptation and mitigation. This duality of response is very well summarised in the statement from Parry *et al*. (2007):

> *"Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential, particularly in addressing near-term impacts. Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt."*

And, the IPCC (2007a):

> "*Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation, and takes into account climate change damages, co-benefits, sustainability, equity and attitudes to risk*."

The focus of this guidebook is on helping organisations make sense of, and progress with, adapting to climate change, and frames adaptation as an issue of climate risk management.

Table 1.1 Characteristics of mitigation and adaptation. Actor benefits, means the organisation that actually undertakes the mitigation or adaptation action. *Source*: adapted from Füssel (2007).

Characteristic	**Mitigation of climate change**	**Adaptation to climate change**
Target systems	All systems	Selected systems
Scale of effect	Global	Local to regional
Lifetime	Centuries	Years to centuries
Lead time	Decades	Immediate to decades
Effectiveness	Certain	Generally less certain
Ancillary benefits	Sometimes	Often
Polluter pays	Typically	Not necessarily
Actor benefits	Only little	Almost fully
Monitoring	Relatively easy	More difficult

1.2 Adapting to climate variability and change

Adapting to climate variability and change is an issue of climate risk management, where an organisation seeks to reduce any potential threats, and make the most of any opportunities that may arise as a result of climate change. This risk management entails developing and implementing adaptation strategies and actions. Adaptation is however, a complex, highly context specific, multifaceted issue. Aspects of adapting to climate change range from having or developing an awareness of the need for adaptation, and understanding the adaptation issue at hand, planning strategies and actions for dealing with these issues, implementing them, and then monitoring and reviewing their performance, as well as the risks themselves, as they change over time. Adaptation then is a continuous process of awareness and understanding, planning, implementation, and monitoring and review (Moser & Ekstrom 2010).

Each of these different aspects or phases of adaptation require the application of different methods, approaches and skills, in order to make progress. In the awareness and planning phases making progress may largely depend on generating an information or evidence base and understanding of how a given system functions in order to inform the development of effective adaptation strategies. At the implementation phase however, making progress may largely depend on a number of institutional, organisational and general governance issues (Berkhout 2011, Wilby & Vaughan 2011). Ensuring that suitable monitoring systems are either already, or put into place, and that performance of adaptation strategies and risks are periodically reviewed, will largely depend on organisational issues relating to adequate resourcing. It is however, important to state that at all phases, the importance of stakeholder dialogue and engagement, should be appropriately considered (Rotter *et al*. 2013). Moreover, whilst the emphasis on the use or relevance of a particular method or approach may shift from one phase to the next, the different phases are clearly interrelated, and should not be viewed or addressed with compartmentalized analysis. Accordingly, it should be clear that adaptation is a social process, where the ingredients for success are many and varied (Moser and Boykoff 2013).

1.2.1 Adaptation as risk management

This guidebook frames adapting to climate change as an issue of climate risk management. We adopt the ISO 31000:2009 definition of risk, as being: “The effect of uncertainty on business objectives”, and risk is calculated as the product of the likelihood of a climate-related event, and the consequences. Risk can have both negative and positive consequences, which in this guidebook are referred to as threats and opportunities, respectively. All organisations, be they in the public or private sector, will have business plans and objectives, some of which may be affected by, or sensitive to climate-related events. Use of this language and concept of risk is used throughout this guidebook, and business objectives are taken to mean the values, goals, and targets that any organisation may have or desire to obtain.

These objectives can be analysed as to the effect that climate and other relevant factors e.g. socio-economic and socio-political, may have on their successful achievement. A risk management framework provides a means within which to systematically analyse these risks, understand how they are generated as a result of the interaction of climate and non-climate factors, what the negative and positive consequences may be, and how we may be able to intervene to reduce threats and make the most of any opportunities. The risk management framework as applied to adaptation is shown schematically in figure 1.1.

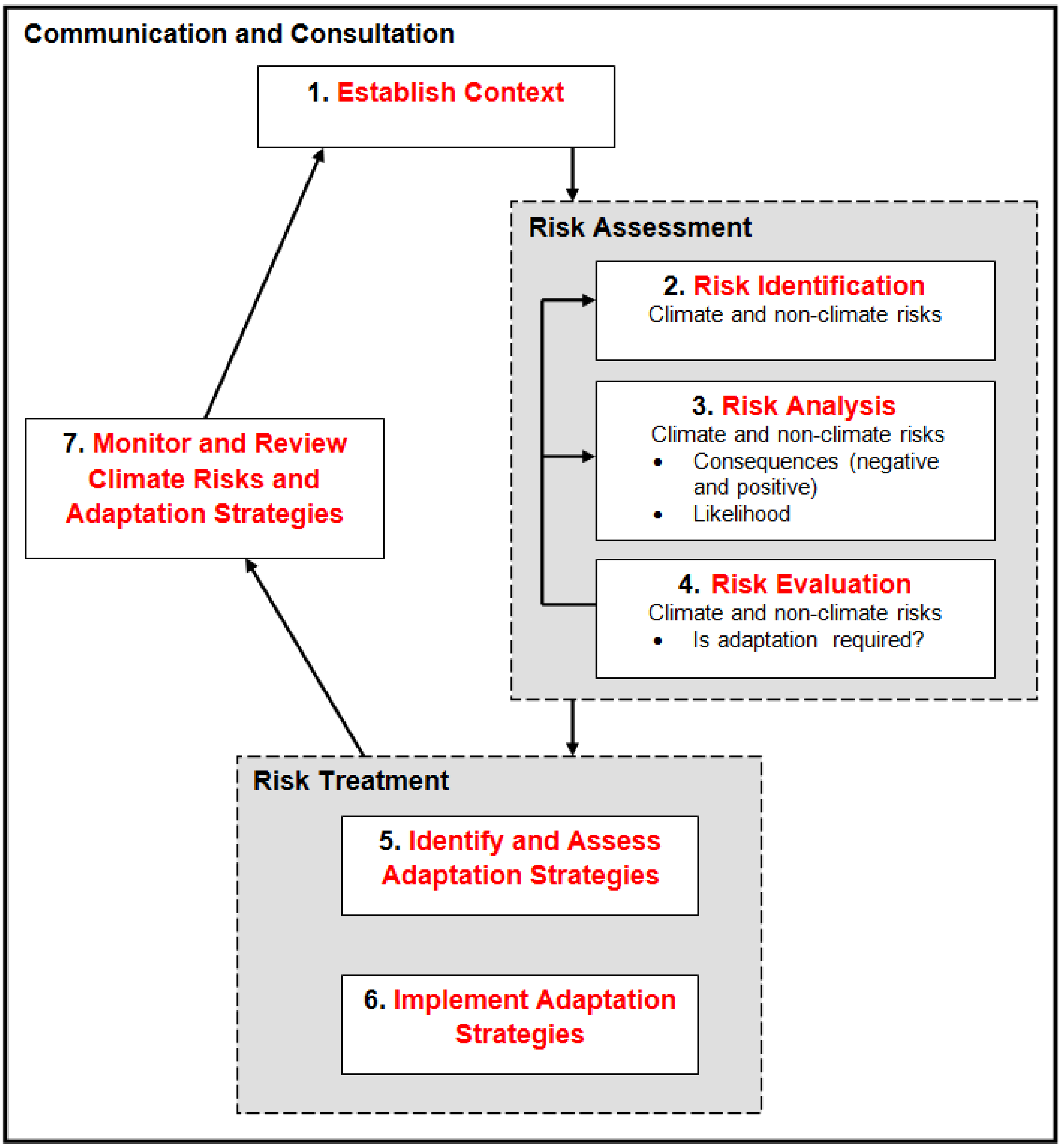


Figure 1.1 Schematic representation of adaptation as a process of risk management. *Source*: adapted from ISO31000:2009.

Box 1.1 Glossary of terms and concepts used

Various terms and concepts are used throughout this guidebook, and the key terms are defined below.

Adaptation: involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting nonclimatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities (Moser & Ekstrom 2010).

Adaptation assessment: The practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency and feasibility (IPCC 2007b).

Adaptive capacity: the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007b).

Climate-related event: the way in which organisations are affected by climate change will be expressed through direct changes in climate variables such as temperature and precipitation, but also through changes in extreme events such as heatwaves, droughts, storms, flooding and wildfires. To aid the clarity of the text, we use the term climate-related event to refer to these different changes.

Decision-relevant information: is that which yields greater insight or understanding of an issue, which hopefully leads to better decisions being made (NRC 2009).

Model: an abstraction or simplification of how we understand a real world system to work. The development and use of models is an essential part of the risk assessment stage of the risk management framework.

Risk: the effect of uncertainty on objectives (ISO 31000:2009). Risk is calculated as the product of the likelihood and consequences of a climate-related event. Risk entails both negative and positive consequences, which may present threats and opportunities to an organisation.

Risk management: the systematic application of management policies, procedures, and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring, and reviewing risk (ISO 31000:2009).

Robust decision making: a decision making framework which acknowledges our inability to predict the future with certainty, and thus seeks to minimise the regret associated with a given adaptation strategy, rather than seeking to develop an optimal strategy.

Scenario: a plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships IPCC (2007b).

Stakeholders: individuals, groups or organisations who can affect or be affected by the results of a decision (based on Freeman 1984).

Vulnerability: the propensity or predisposition to be adversely affected (IPCC 2012).

1.2.2 Approaches to adaptation: "top-down" or "bottom-up"?

In the adaptation research arena there has been considerable discussion around the merits of what is known as a "top-down" or impacts-first approach to adaptation planning, in contrast to a more "bottom-up" thresholds-first approach, in providing decision-relevant information (Carter *et al*. 2007, Wilby & Dessai 2010). Decision-relevant information is that which yields greater insight or understanding of an issue, which hopefully leads to better decisions being made (NRC 2009). The "top-down" approach typically sees the application of a range of different quantitative models to the study of climate risks, and then seeks to identify adaptation strategies from these results. However, this approach is generally not structured around key thresholds or business objectives that may be important to an organisation, and as such, the analysis takes place in the absence of a well-defined decision making context, and consequently yields little insight to the decision making process. In contrast, the "bottom-up" approach, seeks to understand the organisational context and causes of the way in which climate risks arise and why they are important, and is duly more grounded in the real-world of decision making, and thus may provide more decision-relevant information than a "top-down" approach. Accordingly, the classical "top-down" approach is not well suited to informing adaptation planning in practice.

It is however the case, and increasingly recognised, that the kinds of models that are typically associated with the "top-down" approach, can, and indeed should, be combined with the "bottom-up" approach when considering adaptation strategies or actions, that may play out over a number of decades (Lal *et al*. 2012, Turner *et al*. 2003). The issue is not the use of models themselves, but rather the way in which the analysis is structured i.e. around objectives and thresholds that are important to an organisation. In this guidebook, a risk based approach to adaptation is taken, which is an inherently "bottom-up" process, being as it is, concerned with the effect of uncertainty on business objectives. The use of models and climate data is entirely consistent, and indeed necessary to pursue this approach. These issues are summarised schematically in figure 1.2. As such, this guidebook seeks to provide a framework for the intelligent synthesis of the "top-down" and "bottom-up" approaches (Mastrandrea *et al*. 2010a).

1.3 Climate change, climate impacts and climate-related events

Various metrics or indicators are used to monitor how the climate has and is changing (Blunden, & Arndt 2013), and a number of these are shown in figure 1.3. All of these indicators in figure 1.3 are consistent with what one would expect under a warming world. Typically, however, the indicator of choice when searching for evidence of a changing climate is the global annual mean surface temperature change, and this is shown in figure 1.4. Clearly, observations of surface temperature show that the Earth has warmed, and over the period 1880 to 2012 the global average land and ocean surface temperature has warmed by 0.85^{o}C (IPCC 2013). Figure 1.4 also shows that while the annual average may display a spiky pattern – with some years being warmer or colder than the preceding one, when taking a longer view and averaging over a decade, the last three decades have been successively warmer than any preceding decade since 1850 (IPCC 2013).

Climate model projections indicate that the Earth will continue to warm over the course of the 21st century. Projections from the AR5 suggest an increase in global mean surface temperature in the time period 2081-2100 of 0.3^{o}C to 4.8^{o}C, relative to 1986-2005 (IPCC 2013). As the Earth warms, this also has implications for sea level rise. Projections of global mean sea level rise from the AR5, suggest that global mean sea level in the time period

2081-2100 may increase by between 0.26 m and 0.82 m, relative to levels in the time period 1986-2005 (IPCC 2013).

Clearly, these changes in climate will have a range of impacts on economic, social, and ecological systems. Figure 1.5 provides a summary of potential global climate impacts in a number of economic sectors, for a range of changes in global annual mean surface temperature. These impacts are summarised at the global level, and are intended to provide examples that will help stimulate awareness and analytical thought about how a given organisation may be affected by these and other impacts, rather than trying to be specific about what may happen in a given region. A summary of changes in climate and potential impacts in Germany is available in Zebisch *et al*. (2005).

The way in which an organisation may be affected by changes in climate is not only through direct changes in climate variables such as temperature and precipitation, but also changes in extreme weather events, such as heatwaves, droughts, storms, flooding and wildfires. A changing climate may influence the frequency and magnitude of such extreme events (IPCC 2012). As such, under a changing climate these events may either serve to exacerbate existing climate risks, and/or generate new ones, that an organisation will need to adapt to.

To aid the clarity of the text in this guidebook, we use the term climate-related event throughout, to refer to both weather events and extremes, and the direct changes in individual climate variables that may generate impacts in different economic, social, and ecological systems.

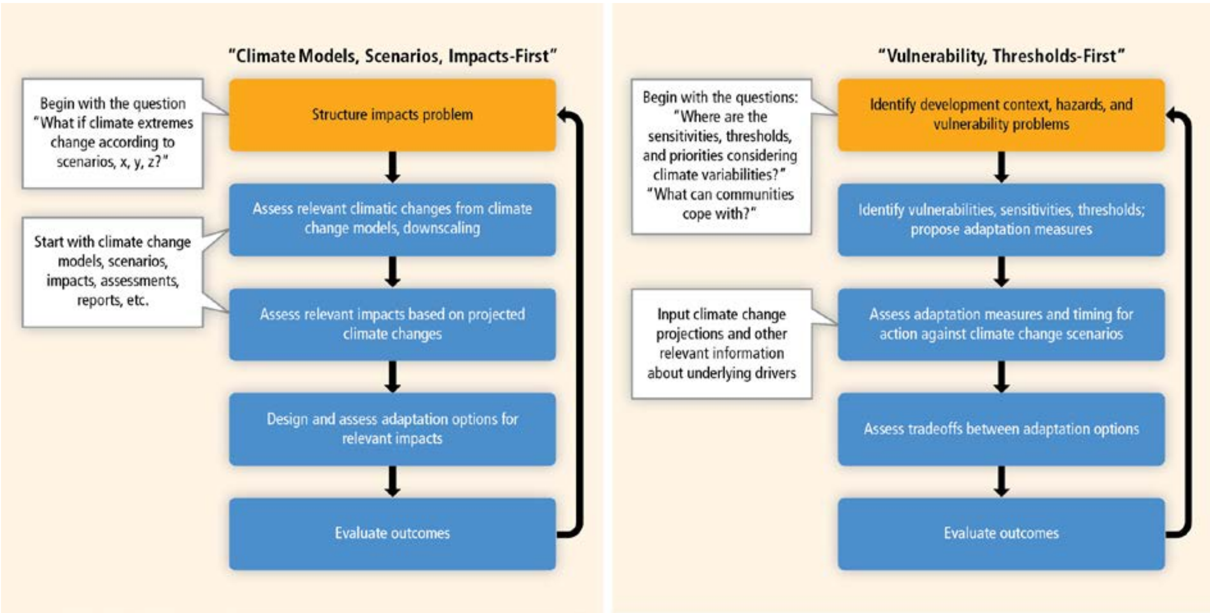


Figure 1.2 Schematic of the different methodological structures of the conventional "top-down" or impacts-first, and "bottom-up" or thresholds-first, approaches to adaptation. Source: Lal et al. (2012).

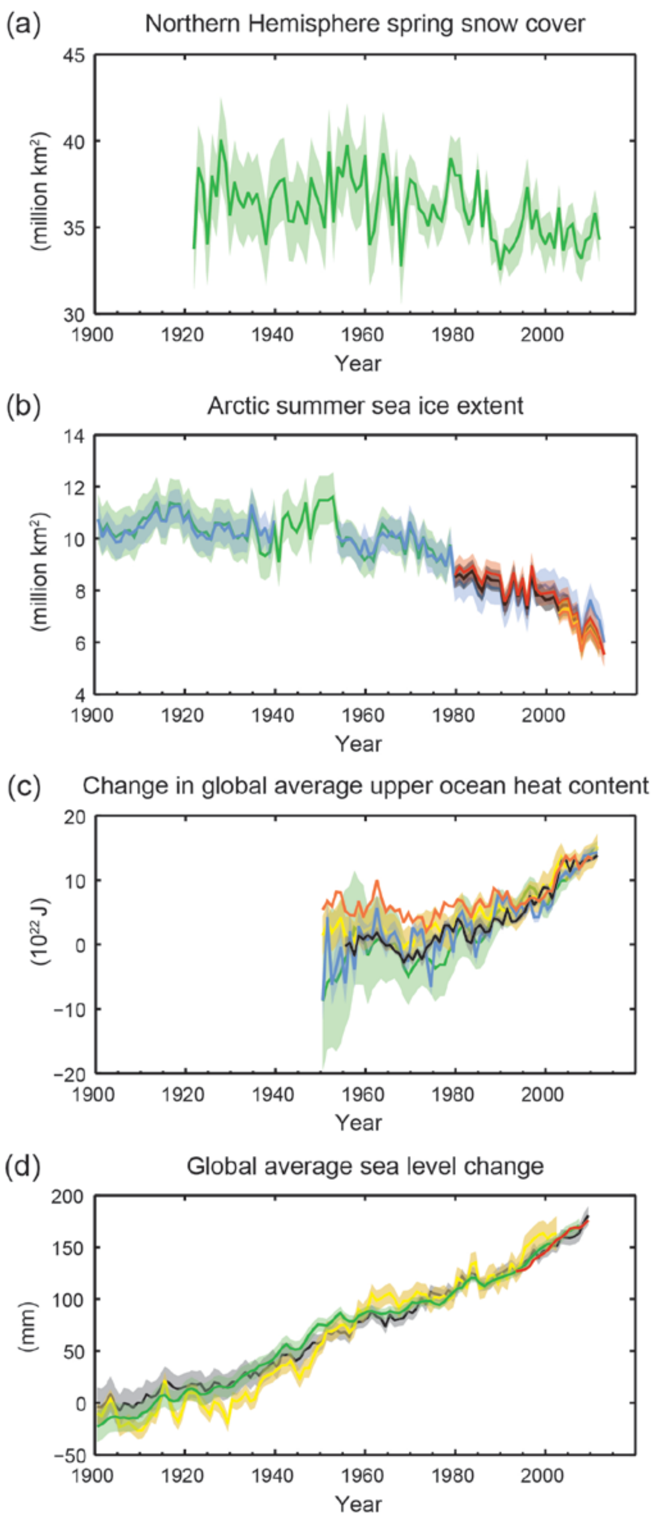


Figure 1.3 Multiple observed indicators of a changing global climate: (a) Extent of Northern Hemisphere March-April (spring) average snow cover; (b) extent of Arctic July-August-September (summer) average sea ice; (c) change in global mean upper ocean (0–700 m) heat content aligned to 2006−2010, and relative to the mean of all datasets for 1970; (d) global mean sea level relative to the 1900–1905 mean of the longest running dataset, and with all datasets aligned to have the same value in 1993, the first year of satellite altimetry data. All time-series (coloured lines indicating different data sets) show annual values, and where assessed, uncertainties are indicated by coloured shading. *Source*: IPCC (2013).

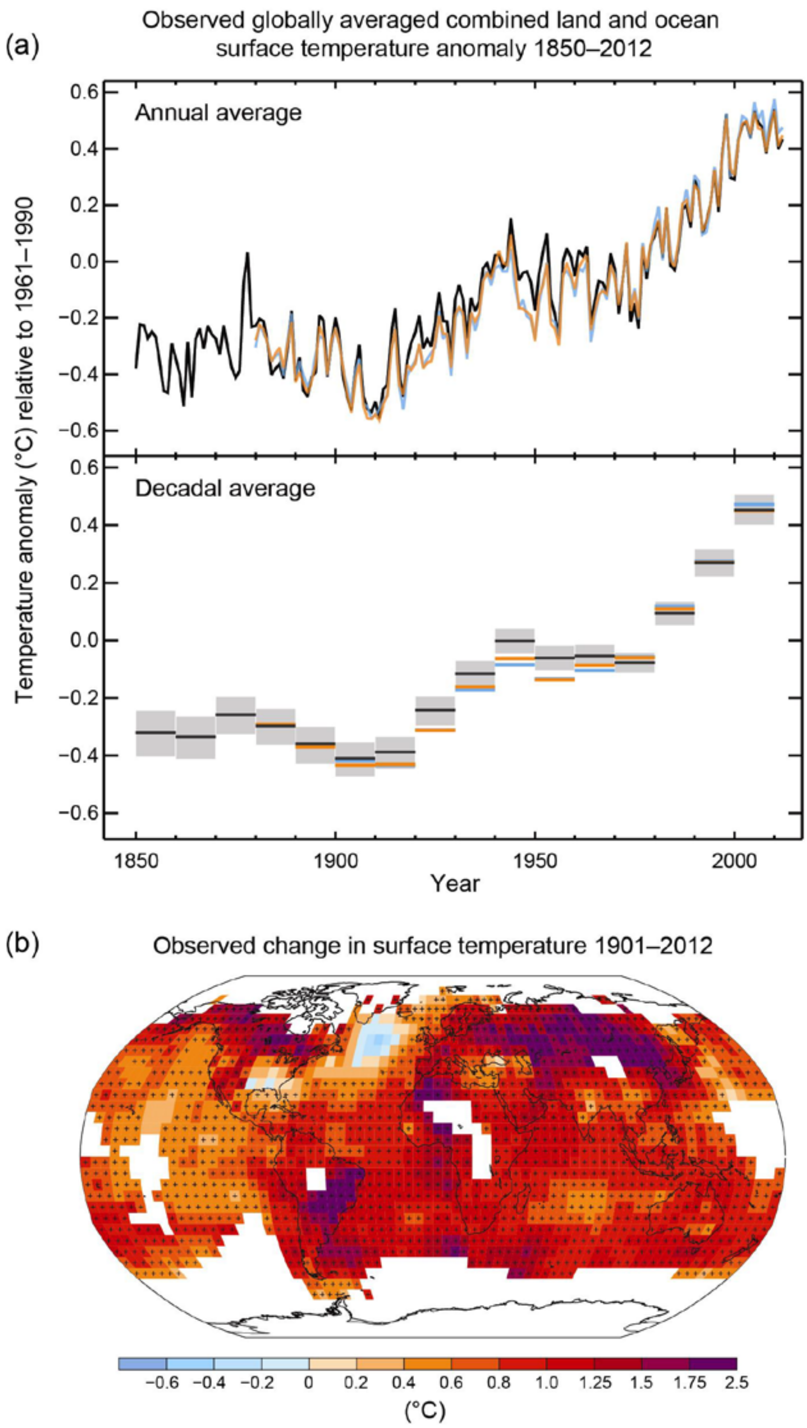


Figure 1.4 (a) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 1961−1990. (b) Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset (orange line in panel a). Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign. *Source*: IPCC (2013).

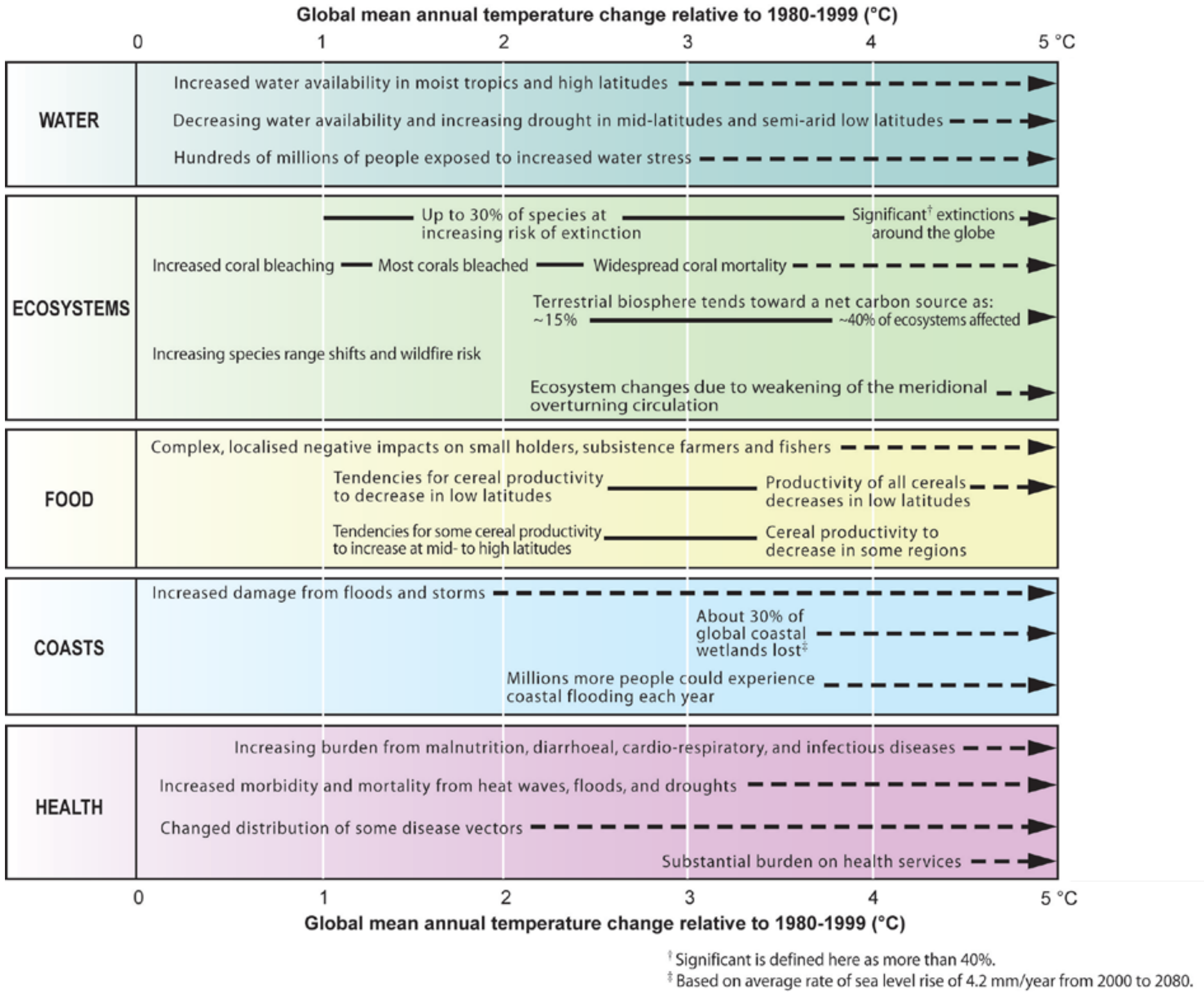


Figure 1.5 *Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts, dotted arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of the text indicates the approximate onset of a given impact. Quantitative entries for water stress and flooding represent the additional impacts of climate change relative to the conditions projected across the range of Special Report on Emissions Scenarios (SRES) scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. All entries are from published studies recorded in the chapters of the Assessment. Confidence levels for all statements are high. Source*: IPCC (2007c).

1.4 Making the case for adaptation

The impacts of climate change as expressed through climate-related events, are many and various, and may present new risks and/or make managing existing risks more challenging (IPCC 2007a). These risks may be strategic, operational, compliance, or reporting risks, and the impacts of climate change can occur in a range of different areas of an organisation's activities, including: processes, people, premises, finance, logistics, and markets (UKCIP BACLIAT). For example, in the private sector, a manufacturer may experience a local flooding event which means that a factory is inoperable for a period of time, causing losses in production, as well as any damages (insured or otherwise), to the business premises. Clearly, potential financial consequences from such an event could be very significant.

Moreover, in today's increasingly interconnected globalised world, a flooding event in another part of the world may have an impact on a manufacturer's supply chain (CDP 2013). A recent example would be the flooding in Bangkok, Thailand, in 2011, which caused major disruption and damages to the automobile and electronics industries across the world (World Bank 2012b). This example serves to highlight that organisations seeking to adapt to climate change, may need to consider impacts both locally and internationally, in order to manage their climate risks effectively. This example also serves to highlight the potential that may exist for integrating adaptation planning and climate risks, into any existing business continuity and/or contingency planning activities. In the public sector, climate-related events can impact a range of different service areas including welfare services, transport, infrastructure, and urban and regional planning. As such, climate, and potential changes in climate, should be considered in planning these activities.

The questions that any organisation which is motivated to learn more about, or start to take action in relation to adaptation, will likely include:

1. What kind of climate-related events and impacts is my organisation affected by today?
2. How may my organisation be affected by climate-related events and impacts in the future?
3. How often do these events happen today, and how may their frequency and magnitude change in the future?
4. How significantly is my organisation affected by climate-related events today? How may this significance change in the future?
5. Could my organisation be affected by new or emerging impacts under climate change?
6. What are the causal factors that make my organisation susceptible to the impacts of climate-related events?
7. How soon might my organisation need to adapt?

These are all questions that will need answering in order to establish a sound footing on which to start to make progress with adaptation. Before asking these questions however, organisations may need to be persuaded of the need for, or benefits of undertaking adaptation. Clearly, some organisations may already know that their organisation is sensitive in some way to climate-related events, and may already have experienced the impacts, and thus be aware of the need for adaptation, and be motivated to take action. However, many organisations may not be aware if they have climate sensitive business areas, and for whom awareness of the need for adaptation may not exist, and as such may need to be persuaded that it is something that they should allocate resources to. The climate has changed and will continue to change. Under climate change, an organisation that has climate sensitive business areas will likely be more susceptible to climate-related events in the future. There are a number of reasons why it makes good sense to start thinking about and making progress with adaptation to climate change. These include:

1. **Climate non-stationarity**. Many existing management strategies, regulations and standards in a range of activities from water resources management to building regulations, have operated under the assumption that the climate was well known and varied within a certain well defined range, based on past observations and experience. Under climate change, we can no longer assume that the past climate is a reliable guide to future climate. This is what is referred to as climate non-stationarity (Milly *et al*. 2008). As such, climate non-stationarity may represent the end of business-as-usual. Consequently, existing management strategies may need

updating in the light of this new knowledge, or at the very least, should be tested to see how they may perform in the future, under climate change, and whether or not business objectives and targets can continue to be met.

2. **Co-benefits with existing business objectives**. Adaptation may sometimes be seen as thinking about climate change that may happen a long time in the future, and as such, can often be deemed to be low priority, in relation to other factors in the business environment, and thus not acted upon. However, starting a process of thinking about how an organisation may be impacted by climate-related events, and considering future risks, may lead to the identification of strategies or ideas which can have immediate benefits to an organisation, as well as ensuring that future activities are more resilient in the face of change. These changes could for example, lead to the use of a different technology, which both reduces costs now, and makes an organisation less susceptible to current, and future climate-related events.
3. **A business opportunity and ensuring future viability**. While the focus of the discussion on climate change typically centres around the threat that it poses, and thus the seriousness of the problem, this doesn't mean that there won't be opportunities. Indeed, if we are to be able to adapt then this will require effective solutions – products and services – from both the public and private sector. An example could be that under a different climate, patterns of consumer behaviour may change, opening up or closing down markets, it would be good sense to know what may be likely to happen, or at least what the possibilities may be. It is general good business practice to be aware of emerging opportunities for business development, and climate change is a major driver of change in the business environment, and this can lead to opportunities but may also lead to changes in the regulatory environment which you may need to respond to.
4. **Cost effective**. It is often more cost effective to deal with any business threats as they arise, rather than allowing them to develop into bigger problems. The cost of action after the event, or when changes become clearly evident is typically achieved at much greater cost, than acting ahead of time.
5. **Competitive advantage**. Being an early mover in any kind of market (private or public), can ensure that you are ahead of the game in terms of product or policy development, and well placed to seize opportunities as they arise, and reduce or avoid any potential threats.
6. **Reputation and image**. Being seen to be in tune with, and responding to the issues of the day can be good for your image, especially if you operate in an environment where such issues are important, in terms of stakeholder relations, and consumer and public perception. Moreover, it can also improve your perception as being a good employer, helping to attract and retain good staff.
7. **Investor sentiment**. Being active in relation to climate change and the various risks it may pose to your organisation, are issues that are of increasing relevance to securing financial investment. As the general awareness of climate change within society increases, investors are becoming more demanding of organisations, and increasingly want to see climate risks disclosed and reported in an organisation's risk profile.

1.5 About the guidebook

1.5.1 What is the purpose of this guidebook?

Whilst the general level of awareness of climate change and the need for adaptation may be increasing among some organisations, the task of actually making progress in dealing with adaptation issues is a complicated one. For many organisations, dealing with climate may represent a completely new issue, and for others a changing climate may present new challenges to existing risk management practices. In order to answer the kinds of questions listed in section 1.4, organisations may generally not know where to start, or be unaware of what their options are for generating an evidence base upon which to act. As such, there is a major need for guidance and support.

This guidebook seeks to provide organisations with the information they need in order to understand the range of issues involved in adaptation, and to make informed decisions about how they may make progress with adaptation planning in practice. The guidebook does not make recommendations about particular adaptation strategies or actions to pursue. The range of adaptation problems is so diverse, complex, and context specific that it is simply not meaningful to do so.

This guidebook works on the basis that a sound understanding of the functioning and sensitivity of a given social-ecological system to variation in both climate and non-climate factors, is key to being able to develop coherent adaptation strategies and actions. As such, the guidebook has a focus on describing a range of methods and tools that can be applied when carrying out a climate risk and adaptation assessment, and associated issues with their application, chief among which is the implication of uncertainty for adaptation decision making. Accordingly, this guidebook is most useful in relation to raising awareness of the need for adaptation, and in establishing an evidence base of decision-relevant information to help inform the development of strategies and actions in the adaptation planning process.

1.5.2 Aim and objectives of the guidebook

The aim of this guidebook is to provide a clear, accessible, and wide ranging introduction to the issue of climate change adaptation, which users may use to help them make sense of and progress with adaptation planning. As such, it should help users navigate the complex adaptation terrain, as they proceed along their adaptation journey. The guidebook has the following objectives:

1. To introduce the topic of, and explain the necessity for adapting to climate change.
2. To introduce users to the idea that adaptation is an issue of climate risk management.
3. To equip users with the knowledge they need in order to make more informed decisions about how to get started with adaptation, and the range of methods and tools that may be applied to carry out a climate risk and adaptation assessment.

1.5.3 Who is it written for?

This guidebook is written for managers, analysts, and decision makers in the private and public sector. A range of different professionals may already be engaged in climate or environment related activities within their organisation e.g. on mitigation or sustainability issues, but for whom adaptation may be new, and something they wish to learn more about. This guidebook will also be informative for higher level decision and policymakers interested to learn more about the need for, and issues involved in adapting to climate change and variability. Although the guidebook has been written in such a way as to make the text as accessible and easily understandable as possible, there may be places where some basic knowledge of climate change, and concepts relating to scientific modelling, and a general scientific literacy will be helpful.

1.5.4 Structure of the guidebook

This guidebook consists of six main chapters, and two appendices. Most chapters begin with a summary of the issues that will be addressed, and finish with a summary of the key points that should come through after having read the chapter.

Chapter two provides a question and answer style presentation of 20 key questions that users may have or need to know about adaptation. The aim is to introduce the full breadth and scope of issues that are relevant to adaptation in an engaging style. **Chapter three** presents a detailed discussion of the risk management framework as applied to adaptation. This chapter also discusses models and uncertainty, and the critical need for causal models in risk assessment. **Chapter four** provides a wide ranging discussion of a number of different methods and tools that may be used at the risk assessment and adaptation assessment phases of adaptation. **Chapter five** provides a discussion of the ways in which adaptation strategies may be developed, methods, tools, and approaches that may be applied, and the implications of uncertainty for making adaptation decisions. **Chapter six** provides an annotated description and links to sources of further information for the main issues that are raised in each chapter, such that the reader interested to learn more about a particular topic, is guided on where to look to find such information.

2 Adaptation to Climate Change: 20 Questions

Chapter Highlights

- Provides a comprehensive coverage of the wide ranging issues involved in adaptation, in a conversational Q&A style.
- Will assist users in developing their understanding of the various issues involved in adaptation.

2.1 Introduction

Adaptation to climate change is a highly context specific and complex topic, that is still relatively new to many organisations. There are a range of different issues involved in adaptation from being able to generate an awareness of the importance and relevance of the issue, to planning, implementation, and monitoring and reviewing adaptation strategies and actions. The complexity of the issues involved may often seem bewildering to practitioners and newcomers alike, and thus being able to make progress with adaptation may sometimes appear rather daunting. The purpose of this chapter is to provide a wide ranging discussion of a number of issues that are central to adaptation thinking. The aim is to help provide a means with which users can familiarise themselves with the issue of adaptation, and orientate themselves in terms of how they may start to make progress. We present the discussion in a conversational Q&A style, in order to try and make the material more accessible and meaningful.

2.2 20 questions

2.2.1 What is adaptation to climate change and variability?

Essentially, adaptation involves taking action in response to the impacts of climate change in social, economic and ecological systems, to minimise any threats and maximise any opportunities that may be presented by a changing climate. Adaptation is an iterative social process of defining a problem, planning and implementing action, and monitoring and reviewing these actions, in the light of new or changing risks, regulations, policies, and/or new information or improved understanding or learning about how a given system functions. These various stages can be handled very effectively within a risk management framework, and this is the approach taken in this guidebook.

Adaptation action involves making changes in management practices and business systems in order to reduce the threat of potential for harm or negative consequences, and maximise or exploit any opportunities or positive consequences that climate change may provide. These actions may range in size from relatively small changes, or larger transformations, depending on the size and scale of the adaptation problem (Kates *et al*. 2012, Vermeulen *et al*. 2013). These actions may take place in order to cope with the impacts of climate change over the shorter term, or to ensure that business objectives are able to be met over the longer term, and thus will involve long-term forward planning. Moreover, adaptation to climate change isn't just about thinking in terms of how the climate may change in isolation. Adapting to the impacts of climate change should be integrated into all business operations, and thus any adaptation actions will need to fully consider the non-climate factors that are key to understanding the impacts of climate change in their proper context i.e. the relevant socio-economic and socio-political factors. Only by doing this, will a sound foundation be laid for developing adaptation strategies and actions.

It is also important to state that adaptation may not be successful. The success of adaptation will depend on a wide range of factors including the size and/or complexity of the problem that we are dealing with, good governance structures, adequate resourcing, a sound understanding of how a given system functions, and appropriate incentives. Chief among these factors will likely be the size of the problem that we are dealing with, which serves to highlight the importance of rapid reductions in carbon emissions through mitigation activities (Warren *et al*. 2013). The larger the changes in climate and associated impacts that we have to deal with, the less likely it is that adaptation will be successful as the physical, technical and social limits of adaptation are reached. This issue of limits to adaptation is discussed in more detail in section 2.2.14. The foregoing discussion leads to a suitable definition of adaptation as:

> "*Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting nonclimatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities*."
>
> Moser & Ekstrom (2010)

2.2.2 What are we adapting to?

Over the short term it is the impacts from weather events, whereas over the longer term it is adapting to both climate variability and change. These changes may be made manifest through changes in the incidence and magnitude of extreme weather events, or changes in the mean climatology in a given area (IPCC 2012). In this guidebook we use the term climate-related events, to refer to these changes.

What we really need to know however, is how these changes in climate and weather may affect the systems that we care about, and how organisations are able to continue to fulfil their climate sensitive business objectives. To illustrate some of the kinds of impacts that organisations may need to adapt to, figure 2.1 summarises some possible climate impacts that may occur in different economic sectors, as a result of climate-related events. It should be pointed out that there is a large amount of uncertainty on these possible impacts, both in terms of their magnitude, and occurrence. Nevertheless, these examples provide a valuable stimulus to thinking about possible impacts that an organisation may be affected by.

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems [4.4, 5.4]	Water resources [3.4]	Human health [8.2, 8.4]	Industry, settlement and society [7.4]
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snow melt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g., algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially-isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	Likely	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property
Increased incidence of extreme high sea level (excludes tsunamis)[c]	Likely[d]	Salinisation of irrigation water, estuaries and freshwater systems	Decreased freshwater availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

[a] See Working Group I Fourth Assessment Table 3.7 for further details regarding definitions.
[b] Warming of the most extreme days and nights each year.
[c] Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
[d] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period [Working Group I Fourth Assessment 10.6]. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Figure 2.1 Examples of possible impacts due to climate related events, based on projections to the mid- to late 21st century. *Source*: IPCC (2007c).

2.2.3 Are there different kinds of adaptation?

Yes there are. Adaptation to climate change is an activity and process that has many different characteristics, and these are summarised in figure 2.3 (Smit *et al*. 2001). The purpose of adaptation can be, for example, autonomous or planned, and the timing of the adaptation can be anticipatory or responsive. Autonomous adaptation is defined by the (2007b), as:

> *"Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems."*

Whereas, planned adaptation is defined by the IPCC (2007b) as:

> *"Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state [business objective]."*

Stated simply, autonomous adaptation is an adjustment (or change) that occurs **without the direct action of humans**, whereas planned adaptation, takes place **with the direct action of humans**. Responsive adaptation is that which takes place **during or after the impacts** of climate change have been observed, in contrast to anticipatory adaptation, which takes place **before the impacts** of climate change have been observed. The focus in this guidebook is needless to say on planned adaptation.

Adaptation will also take place over a range of spatial and temporal scales, from the local to the regional, and over the short- or long-term. When developing adaptation strategies and actions to deal with climate risks, these may be characterised according to their intended function. This function, using risk management terminology, may include reducing, accepting, spreading or transferring the risk.

In addition to the function of a given adaptation action, they may take a particular form. For example, in order to be able to maintain future water supply to a city or region, a water company may decide to take a technological action and build a new reservoir. This same adaptation problem could also be addressed through a 'soft' option of trying to manage the demand side of the problem, by educating customers to consume less water.

Having considered or developed a number of different adaptation options, it will be necessary to be able to choose between the different actions, and this assessment may be based on a range of performance criteria, including cost, efficiency, and equity. This issue of choosing between adaptation strategies or actions is discussed in more detail in chapter 5.

2.2.4 How are we able to adapt?

Our ability to adapt to climate change is largely expressed through the concept of adaptive capacity. Adaptive capacity is defined by the IPCC (2007b) as:

> *"The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences"*

Adaptive capacity is largely determined by the availability of economic resources, technology, information and skills, infrastructure, institutions, and equity to which a given organisation has access to (Smit *et al*. 2001). The level of adaptive capacity that an organisation has will play a major role in the evaluation of the significance of climate risks, and also in the development and implementation of adaptation strategies and actions. The success of adaptation planning and ensuing adaptation strategies and actions, will be due to a range of factors, including awareness, system understanding, and associated uncertainties involved, stakeholder acceptance, and the level of resources available. The issue of successful adaptation is dealt with in more detail in section 2.2.19.

General Differentiating Concept orAttribute	Examples of Terms Used
Purposefulness	Autonomous ↔ Planned Spontaneous ↔ Purposeful Automatic ↔ Intentional Natural ↔ Policy Passive ↔ Active Strategic
Timing	Anticipatory ↔ Responsive Proactive ↔ Reactive *Ex ante* ↔ *Ex post*
Temporal Scope	Short term ↔ Long term Tactical ↔ Strategic Instantaneous ↔ Cumulative Contingency Routine
Spatial Scope	Localized ↔ Widespread
Function/Effects	Retreat - Accommodate - Protect Prevent - Tolerate - Spread - Change - Restore
Form	Structural - Legal - Institutional - Regulatory - Financial - Technological
Performance	Cost - Effectiveness - Efficiency - Implementability - Equity

Figure 2.2 Bases for characterising and differentiating adaptation to climate change. *Source*: Smit *et al*. (2001).

2.2.5 How do I know if my organisation needs to adapt?

Firstly, you need to know whether there are areas of your business operations which are sensitive to climate. If you know this perhaps from past experience and/or observation, then a useful concept for trying to understand how climate change and variability may impinge on a business objective is the concept of the coping range.

The coping range defines the upper and lower bounds of climate variability within which the climate has no material negative consequences on a given business objective. Beyond this range, critical thresholds may be exceeded, and a given business objective may be said to be vulnerable. We use the term vulnerability in this guidebook to mean “the propensity or predisposition to be adversely affected” (IPCC 2012). This concept of the coping range and vulnerability is idealized in figure 2.3. The spiky black line could represent daily maximum temperature or daily precipitation, for example. Over time, and under climate change, the variation in a given climate variable may change as shown in the figure, more frequently exceeding the existing coping range, resulting in an increase in vulnerability. With adaptation action, new coping ranges can be established serving to increase the coping range, and reduce the vulnerability.

Understanding the coping range, and establishing information about critical thresholds that may make business objectives vulnerable, is a key part of adaptation planning. It may be possible that company records exist of weather events, or critical thresholds, the occurrence or exceedance of which, lead to a threat (or opportunity) to business objectives. If so, this provides an excellent resource to explore to start to learn and categorise the kinds of thresholds that are important to meeting business objectives. If this information isn't known or available, then a process of risk identification would serve as a suitable starting point for doing so (see chapter 3).

Note
It should be clear that this notion of experiencing conditions beyond which a vulnerability arises (negative consequences), can equally well be applied to the occurrence of an opportunity and potential positive consequences. Similarly the coping range may also be considered to be an area in which the risks are acceptable, in the sense that they can be managed with existing practices.

Understanding the vulnerabilities and critical thresholds that may affect business objectives is clearly useful information. However, simply knowing that an organisation may be vulnerable may not be a powerful enough argument in order to persuade an organisation that they need to adapt. To take action an organisation will likely want answers to a range of different questions, including: how frequently might this event occur in the future? How significant are the impacts of such events in terms of loss or opportunity? How soon may these events occur, or reach a point at which the losses or opportunities are too great to ignore? Adopting a risk management approach to adaptation provides a well-established framework within which answers to these kinds of questions can be obtained.

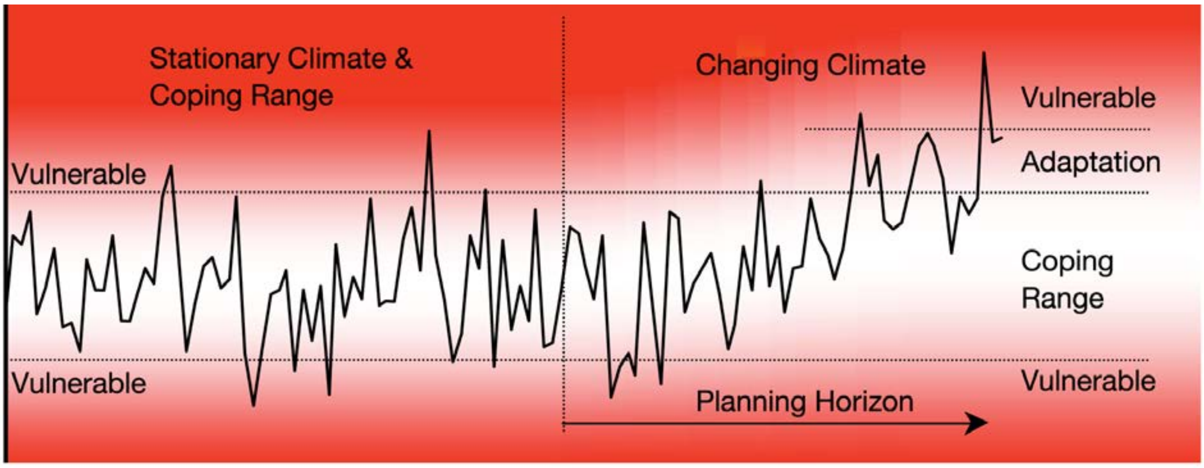


Figure 2.3 An idealized depiction of the coping range, and the concepts of vulnerability and the effect of adaptation serving to increase the coping range to climate events. *Source*: Carter *et al*. (2007).

2.2.6 When does my organisation need to start thinking about adaptation?

There are various considerations which will influence how soon an organisation may need to start thinking about adaptation. An organisation may already have observed or experienced the impacts of climate on their business activities and objectives, and so be well aware of the need to start thinking about adaptation. Another factor to consider is the nature of an organisation's business activities and objectives, and their associated planning horizons (figure 2.4). Climate change, in the absence of major reductions in carbon emissions, is projected to become progressively more significant over time (Solomon *et al*. 2007). If an organisation has business activities which may be affected by changes in climate over a period of say, longer than a decade, then the need to consider long term adaptation and climate change is even greater for these activities than it is for activities which operate over a shorter time horizon.

The planning horizon is the time period over which a given business or investment decision will be operative. For example, the planning horizon for large infrastructure projects would likely be in the region of 50 years or more. Any infrastructure project will be expected to satisfy a range of performance criteria over its lifetime. The effect that changes in relevant climate and non-climate factors may have on the fulfilment of these performance criteria over this time period, should be investigated in the project scope and design phase.

A related issue here is the concept of the decision lifetime. Whilst a given business or investment decision may have a fixed planning horizon, this doesn't mean that the planned solution or strategy need be fixed to the same time period. Because the future is uncertain, and we do not know for sure how much or how soon particular changes in climate may occur, it is advisable, if possible, to incorporate some flexibility into the design of any solutions. This would allow the initial solution to be modified relatively straightforwardly, in the light of new information and learning. Building in this flexibility at the design phase provides a means by which the lifetime of an initial decision can be reduced, thus making the project less vulnerable to uncertainty in how the future turns out (Hallegatte 2009). This would represent sound adaptation planning and should help to ensure satisfactory performance and fulfilment of performance targets and business objectives.

Another issue in making a decision as to how soon an organisation may need to think about adaptation is the notion of the decision lead time, which is the length of time it may take for any planned adaptation strategies and actions to actually be implemented. If, for example, the nature of the adaptation problem is such that it relates to a big infrastructure project e.g. a new road or bridge, then it will inevitably require planning permission and democratic approval, a process which may take many years. Also, once approved, the length of time it may take for a project to be completed and become operational, needs to be considered when thinking about how soon you need to start planning for adaptation. This can very easily mean that decisions made today may take years, and possibly decades before becoming operational, and as such the expected changes in climate that need to be considered will not simply be a function of the planning horizon, but also the decision lead time. Figure 2.4 provides some examples of typical planning horizons for a range of business activities. The same arguments would apply to a decision to build the capacity within an organisation to adapt to climate-related events - these skills are not acquired overnight, and require planning in order that they are acquired in good time.

So, the answer to the question would be that, wherever there are business areas or objectives which are sensitive to climate, there is little reason not to be thinking about adaptation today. This may not mean that you need to start taking action today, but it would be advisable to at least start thinking about it. This thinking could start with creating a better awareness of the issue within your organisation. For example by carrying out an initial process of climate risk identification, and/or risk screening (see chapter 3). This is something which could be performed at relatively low cost, but would provide a foundation for a more informed consideration of the management of climate risks. Moreover the need to consider thinking about adaptation need not be motivated solely by any threats from climate change that need managing, but also by the opportunities that may exist. As such, adaptation could be considered or incorporated as an issue in business development plans.

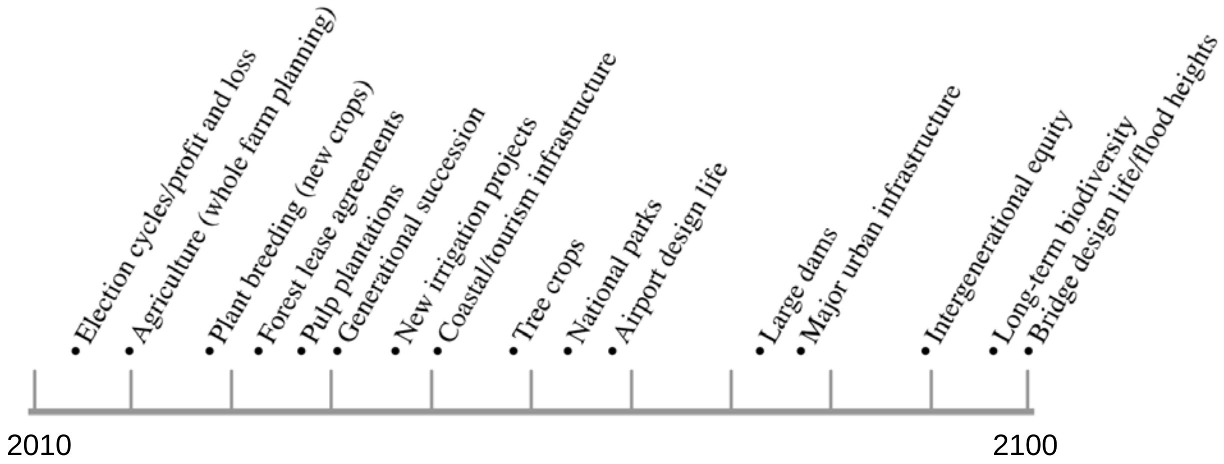


Figure 2.4 Planning horizons of some example business and investment decisions *Source*: adapted from Jones & Mearns (2004).

2.2.7 How soon might my organisation need to take action?

In order to answer this question it is necessary to have first carried out some level of risk assessment, and this is explained in chapter 3. Having done so, it is then a matter of evaluating any risks that may exist to see if they need to be treated. The risk assessment may tell you, for example, that your existing management strategy is likely to perform satisfactorily over the next 10 years, but then will likely run into more difficulty in meeting business objectives. The decision of whether you start to take action to treat this risk will then depend on the level of risk that a given organisation is prepared to accept or tolerate, which will be determined by its risk attitude, and the regulatory environment, among others. This evaluation will also depend on the level of confidence that there is in the results of the analysis. It may be the case that a risk exists, but the evidence for the consequences, and likely occurrence of a given risk, may be such that an organisation decides that it is too uncertain to motivate taking action now, and may instead choose to wait and possibly learn more about how a given system functions, before committing to taking adaptive action. Other issues related to how soon you may need to start taking action, include the planning horizon, as discussed above in section 2.2.6.

2.2.8 What are the sources of uncertainty in adaptation decision making?

There are various and large sources of uncertainty in adaptation decision making these include:

- Uncertainty about the possible future development of human society.
- Uncertainty about the possible future climate.
- Uncertainty in understanding the sensitivity of a given system to changes in climate and non-climate factors, and the impacts these may have on business objectives.
- Uncertainty around the success of any adaptation actions that may be implemented, both in terms of their effectiveness and practicality.

Taken together, these factors mean that in dealing with adaptation, decision makers are faced with such large uncertainties, that there is considerable scope for disagreement as to what the best available strategy may be for taking adaptation action, as such adaptation decision making takes place under conditions of deep uncertainty. Lempert *et al*. (2004), characterise deep uncertainty as being the situation where "*decision makers do not know or cannot agree on: 1) the system models, 2) the prior probability distributions for inputs to the system model(s), and their interdependencies, and/or 3) the value systems used to rank alternatives*". As such, adapting to climate change requires strong stakeholder participation in the decision making process. Chapter 5 provides more discussion of the implications of this uncertainty for decision making.

2.2.9 Is there anything new about adapting to climate change?

In the sense that humans have always adapted to changes in climate and their environment, one could answer no. However, there are some key aspects of anthropogenic climate change, which do introduce new factors. These are (adapted from Füssel (2007)):

1. The rate of change in climate is unprecedented, meaning the challenge of adapting is all the more difficult, as there is less time to adapt to a given change in climatic conditions.
2. Changes in climatic conditions are already or will in the future likely exceed any known conditions in the history of modern humanity, and so we are entering the unknown.
3. We have access to an excellent knowledge base in the form of climate understanding, model simulations, and observations, which we can exploit to help inform adaptation planning, which earlier generations didn't have. It would be a smart move to make use of these resources to help inform and plan adaptation strategies and actions.
4. There is major uncertainty about future climate change, in terms of the direction and magnitude of change for a range of climate variables, and how soon particular changes may happen. This uncertainty in possible changes in climate, are compounded by uncertainties in the impacts that this may lead to. This leads to a situation in which there will likely be varying views among stakeholders of what the most suitable adaptation actions and strategies may be, which complicates the selection and implementation of adaptation strategies. This is a situation in which there is said to be deep uncertainty, and as such this may be something new for organisations to deal with.
5. Climate is no longer stationary. It was typically considered that climate would vary over a fairly well defined range over a period of say 30 years or so, under climate change this notion of stationarity no longer holds. The implication is that any existing management strategies should be tested to see how they will perform in the future

under climate change. This is one starting point for analysing climate risks, section 2.2.20 provides more details on getting started with adaptation planning.

Despite all these factors, the issue of adapting to climate change is something that can and should be integrated into new or existing risk management strategies, such that while there may be different processes involved, the mechanisms and practices for dealing with climate risks are well-established.

2.2.10 What does my organisation need to know or do to make progress with adaptation?

Stated simply, one needs an awareness of the issues involved in adaptation and whether or not your organisation is exposed to climate risks (a process of risk identification). Then, one needs to be able to establish an evidence base upon which the level of any risks (i.e. whether they are significant or not), can be analysed and evaluated. Then, having evaluated these climate risks, any which are deemed to need managing, can be treated by implementing well-chosen adaptation strategies and actions. Finally, having implemented adaptation measures, they will need to be monitored and reviewed, which may require new monitoring and reporting systems to be implemented.

These various tasks are accommodated in the risk management framework adopted in this guidebook, and chapters 3, 4, and 5 provide more detail on these issues. It is important to state that successful adaptation will not be achieved on the basis of one approach or one view of what adaptation is. Different approaches and kinds of information and knowledge will be required at each stage of the risk management process.

2.2.11 How can an evidence base for informing adaptation planning be generated?

Understanding the climate risks that an organisation might be exposed to is best addressed by carrying out a climate risk assessment. This is described in chapter 3, and there are a range of methods and tools available for use, and these are described in chapter 4. Having information on climate risks is a necessary but not sufficient requirement for successful adaptation. Information is also required on what kinds of adaptation actions may be feasible and effective, and developing and deciding between these actions may very often require a process of stakeholder engagement and participation. These issues and various methods and tools that can be applied to help inform this stage of the adaptation process are described in chapter 5.

2.2.12 How do I know what my adaptation strategy options are?

The available adaptation strategies will be determined by the nature of the adaptation problem (size and/or complexity), the level of system understanding, and the various constraints that may make certain options infeasible e.g. stakeholder acceptance, and cost issues. Being able to develop feasible and effective adaptation options will require discussion and negotiation with both internal and external stakeholders. This can take place in the form of holding workshops for example. These options will then need to be appraised as to their desirability, based on a range of criteria. This issue is discussed in more detail in chapter 5. It may also be the case, however, that in the process of carrying out a climate risk and adaptation assessment, that the analysis reveals very obvious adaptation actions that could be implemented immediately, and at low cost.

2.2.13 Do I need to involve other people in adaptation planning?

Yes, you should consider, engage, and communicate with a wide range of stakeholders (both within your organisation, and external). This communication process is a crucial element of any adaptation planning. Firstly, talking to relevant stakeholders provides the opportunity for obtaining as much knowledge and expertise as possible in defining and understanding the nature of the risk and adaptation problem. Secondly, involving relevant stakeholders and having well developed engagement processes can be invaluable in identifying risks, developing feasible adaptation strategies and actions, and also highlighting possible knock-on effects associated with adaptation actions. Further, it may also be the case that potentially effective adaptation actions are prevented from being implemented by existing regulations, and laws. As such, it may be necessary to liaise with regional and national policymakers in order to instigate some mutually agreeable changes in existing regulations, and/or to develop new ones. There are various so-called actors that operate in the adaptation arena, and these are shown in figure 2.5, along with the kind of function they perform in the adaptation arena.

Figure 2.5 illustrates that the adaptation process can and does take place at a range of scales. To illustrate this issue we provide an example of a non-climate-related event, to try and highlight the different scales at which adaptation decision making, may take place.

Consider the risk of an asteroid strike on Earth. At the local level an individual may be aware of this risk, think about it and analyse that the consequences of the event could potentially be very high, but that the likelihood is so low that they don't think any more about it. A different, perhaps more risk averse individual, may decide that they will take some action, and decide to wear a crash helmet every time they are outside. The likely effectiveness of this adaptation action is clearly open to debate. A national government with a duty of care to its citizens may also consider the issue, and decide that their options for actually introducing any kind of effective strategy are severely limited, and that the only realistic way in which an effective strategy could be developed, would be at the global level, in cooperation with the international community. They may then decide to raise this issue at international political meetings, and try to obtain the international will to act. At the global level, if enough nations consider this risk to be serious enough they may be prepared to commit resources to developing an asteroid laser defence system capable of being deployed instantly at any location to destroy or deflect the asteroid (http://goo.gl/LVnSyu), thus removing the threat.

While this may be a light-hearted example, it serves very well to illustrate the way in which different actions may be taken to manage the same risk, depending on the scale at which the risk management is considered, and also differing individual attitudes to risk, and the feasible options available for responding to the threat.

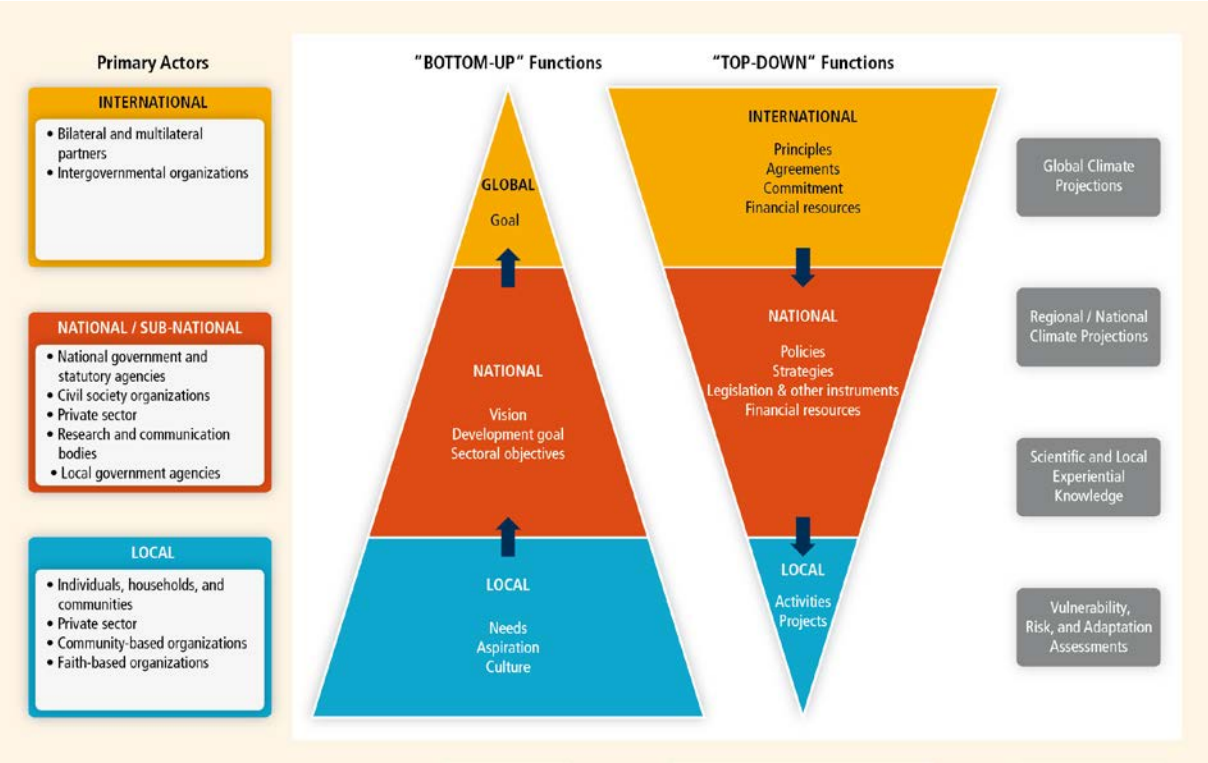


Figure 2.5 Actors and functions in the architecture of adaptation *Source*: Lal *et al*. (2012).

2.2.14 Are there limits to adaptation?

Yes there are. Depending on the current vulnerability of a system, and the possible changes in climate and impacts to which a system may be exposed, it may for a variety of reasons, simply be impossible to adapt successfully to such changes. This could be because it is physically and/or technically impossible, and/or socially or culturally unacceptable (Dow *et al*. 2013). There is a clear link to the mitigation challenge here, because the less effective our mitigation efforts are, the more likely it will be that we are confronted by major climate impacts, which simply present too great a problem to be able to adapt to (Parry *et al*. 2007).

2.2.15 Are there barriers to adaptation?

Yes there are. These are many and various, and include a lack of awareness within an organisation, a lack of knowledge, a lack of organisational buy-in or commitment to adaptation, inadequate financing of adaptation activities due to competing organisational priorities in the business environment, limited skills and adaptive capacity of a given organisation or system, and legislative or institutional barriers. In contrast to adaptation limits which will in general be irresolvable, it is in principle, possible to overcome barriers to adaptation through, for example, building adaptive capacity within an organisation, and through changes in legislation, regulations and incentives (Moser & Ekstrom 2010).

2.2.16 Is adaptation something my organisation only need do once?

Because adaptation decision making takes place under conditions of deep uncertainty, it is really not possible to view adaptation as something that can be done once, and adaptation needs to be viewed as a continuous social process. As new information or learning is obtained, or as risks become more apparent, or adaptation strategies cease to perform effectively, or because of other changes in the external business environment e.g. new legislation or policies, climate risks and adaptation strategies should be continuously reviewed. Adaptation is therefore an iterative process of assessing, treating, monitoring and reviewing climate risks.

2.2.17 How much is adaptation going to cost?

The cost of any adaptation actions will depend on a range of factors specific to each adaptation decision context. If your organisation has climate sensitive business areas, it makes good business sense to at least be informed of the kinds of risks you may face, and thus carry out a risk assessment. Based on the results of this assessment there may be risks that need treating or not, depending on the level of risk, attitude to risk, and the confidence that is placed in the analysis, and how these risks tie in with other business priorities. Furthermore, there may be adaptation options which can be easily implemented at small financial cost, and which make good business sense, regardless of the future climate. A final point to make here would be to turn the question around, and say how much is not adapting going to cost? The answer to this question may provide evidence enough that the cost of adapting makes good business sense. Chapter 5 provides more discussion of the costs of adaptation and ways in which different adaptation options can be appraised.

2.2.18 Is it possible to characterise different kinds of adaptation actions or decisions?

Having made a decision to implement a given adaptation strategy or action, these decisions may be categorised according to the possible impacts or risk they entail. The nature of adaptation decisions will be determined in part by the decision lifetime of any given action, i.e. how long a particular adaptation action may be in place for. Clearly, if the only available action offers little scope for being reversed, then it will have to be lived with for a number of years before it can realistically be modified, or else would involve major cost to do so. Very careful thought is therefore needed when developing and assessing a range of adaptation options (Hallegatte 2009). This issue is discussed in more detail in chapter 5. It is possible to classify adaptation decisions as follows:

- **No regrets**: are those decisions that would yield benefits irrespective of how the climate may change, and as such are less vulnerable to uncertainties in the risk and adaptation assessment.
- **Low regrets**: are those decisions where modest levels of investment may increase coping capacity, and/or are relatively easy or inexpensive to modify or change, if needed i.e. if the future climate turned out to be different from what was planned for.
- **High regrets**: are those decisions where substantial costs may be incurred if the future climate differs from what was planned for, and there is irreversibility (or lock-in) in the adaptation strategy, or can only be reversed at very high cost.

- **Win-win**: these are adaptation decisions that act to reduce or exploit risk, but also have other co-benefits.
- **Flexible, adaptive management**: these are decisions that are taken which offer the scope to be modified easily or reversed, and changed as new system understanding or learning becomes available. These adaptation decisions may be referred to as proceeding along adaptation pathways (Haasnoot *et al*. 2013), and can be a way of reducing the decision lifetime of a given adaptation action.
- **Maladaptation**: these are decisions which serve to increase vulnerability to climate change, or result in lock-in to a particular approach which may be poorly suited to future climate conditions. This issue of lock-in is particularly relevant when considering different adaptation actions. Hard adaptation actions which are typically technological actions, may be prone or at least more susceptible to building in lock-in, than soft adaptation actions. Soft adaptation actions seek a more creative response to the management of climate impacts, through working with existing technologies or implementing different management strategies. An example of the distinction between the two is the management of future water demand, a hard adaptation action would seek to perhaps build more storage capacity e.g. a new reservoir, in order provide more supply, whereas a soft option might seek to reduce the demand for water, by promoting water saving practices.

Ideally, in adaptation we would strive for flexibility in the implementation of adaptation strategies and actions, and operate adaptive management. This may however, not be possible in all cases, depending on the nature of the adaptation problem.

2.2.19 How do I know if an adaptation strategy will be successful?

You don't, but you can increase the chances of success through adequate consideration of a range of factors, when deciding upon adaptation strategies (Moser & Boykoff 2013). Key to successful adaptation is having a well-founded understanding of the way in which a given system functions, and the factors, both climate and non-climate, to which it is most sensitive. If we have this understanding, we can then seek to develop adaptation strategies which will address those factors which are most important in determining system performance. Perhaps the most challenging aspect in adaptation however, is the actual implementation of strategies and actions. Being able to implement adaptation strategies and actions is often strongly dependent on stakeholder acceptance. As such, engaging with stakeholders early and often is a key part of adaptation planning. This engagement could take the form of participatory workshops in which a forum for discussion and social learning is provided. Social learning is that which "*emerges from experience and/or human interaction during which people's different goals, values, knowledge and points of view are made explicit and questioned to accommodate conflicts so that collective action can be taken to tackle a shared problem…[and] leads to a deeper understanding of how complex issues work and why. It improves people's capacity to make sense of and adapt to an ever-changing world.*" (Groot & Maarleveld 2000).

Another way of working towards success is by trying out various different options, monitoring them, reviewing their performance, learning, and then trying out new options or making modifications. This is particularly important if we do not have very high system understanding, or if there is ambiguity about the way in which the system functions. An additional key issue is having the right enabling environment. This relates to having good governance structures, at all relevant levels: within an organisation, a local administration, regional, national, and other levels of government. In addition, building an enabling environment will require incentives for taking adaptation action.

2.2.20 How can I get started with adaptation?

The kinds of questions or activities that might be undertaken in order to make a start with adaptation may include generating an awareness of the issue of climate change. Before more detailed adaptation planning can proceed in the form of carrying out a climate risk assessment, it may be necessary to obtain buy-in from senior managers or the board. This may be achieved by presenting a case which raises awareness of the issue, and explains why adaptation may be important for a given organisation, and the achievement of business objectives. There are various reports both national and international which may be used to initiate a process of awareness raising, and chapter 6 provides links to some major sources of information on climate change.

Clearly, carrying out a process of risk identification is one way in which to get started, and this could start off with trying to understand past and current ways in which operations or activities have been affected by climate-related events. An essential part of being able to manage climate risks effectively is the way in which a given adaptation problem is defined, and the way in which a risk assessment is structured. There are various ways in which the effect that a changing climate may have on business objectives can be made more ‘real’. We have discussed the idea of critical thresholds earlier in section 2.2.5, and this provides a very useful starting point for thinking about the impact of changes in climate.

One issue with the use of critical thresholds however, is that it is often assumed that an organisation knows what these threshold values are, based on experience or knowledge. What if it is the case that an organisation does not know what these critical thresholds are? This concept of thresholds can be equally well applied to being able to meet business targets and objectives. For example, a water company may be required by law to ensure that a certain amount of drinking water is always available to customers. This amount or level of service provision can be thought of in the same way as a threshold - an objective that needs to be met, the achievement of which may be affected by changes in climate. Similarly, a manufacturer of secondary goods may have business operations which are climate sensitive, and have an impact on air quality. This company may have to comply with environmental regulations, this could be, for example, the level of pollutant gases in industrial emissions. This level can be conceived of as a threshold.

For each of these cases, it is possible to ask the question, how might the successful achievement of these objectives be affected by changes in climate? What are the implications of being able to meet these objectives? Will an organisation need to adjust or change its business practices and processes? Structuring the adaptation problem explicitly around business objectives in a risk management framework provides the basis for the generation of decision-relevant information.

As such, one may structure a risk assessment around known critical thresholds, or simply take an existing management strategy which is designed to meet current business objectives, and assess how these would perform in the future, under changed climate conditions. Table 2.1 below provides an example of a business objective and threshold around which a risk assessment could be structured.

Table 2.1 An example of a business objective, a threshold value the exceedance of which may impact upon the success of achieving the said objective.

Business objective or target	Context	Threshold value and reference
Operating a power station at full capacity at all times of the year	Water is often abstracted from rivers in order to provide cooling water for power plants. This abstraction is regulated though, and water may only be abstracted within certain limits. If the water temperature is above a certain level then restrictions on abstraction may be applied and this will impact on the capacity at which a power plant can operate. An energy company may want to know how often this water temperature may be exceeded in the future, and consider what this might mean for the safe and profitable operation of their business.	In Europe, threshold water temperatures for abstraction are 23-28 °C, at which point restrictions may be applied (EEA 2008, van Vliet *et al*. 2012). A risk assessment could analyse how likely such water temperatures may occur in the future, the impact this might have on meeting the business objective, and thus whether or not adaptive action is required.

2.3 Chapter summary

This chapter has shown that:

- Adaptation to climate change encompasses a range of different factors and considerations in planning and implementing adaptation measures.
- Adaptation requires an integrated big picture view of the world, and the various interrelated issues that will determine the chances for successful adaptation.
- Thinking about whether your organisation needs to adapt should start without delay.
- Adaptation is an iterative process, that should become part of all business objectives which may be sensitive to climate-related events.

3 Adaptation as Climate Risk Management

Chapter Highlights

- Introduces the risk management framework, and explains why it is particularly attractive for dealing with adaptation.
- Explains the various stages involved in the risk management process, and the various questions that are important to ask at each stage.
- Introduces the use and importance of causal models in risk assessment, to understand how risk is generated.
- Provides an introductory discussion of the issue of uncertainty as it relates to adaptation decision making.

3.1 Introduction

Adapting to climate change is about taking action in the real world, whereby we seek to reduce any negative consequences or threats, and maximise any positive consequences or opportunities. In order to provide a rational basis upon which to make informed choices about whether we need to adapt, and if so how, we need to be able to understand the ways in which changes in climate-related events (in combination with other relevant factors that contribute to a given problem), may have consequences for a particular business objective, be that in the private or public sector. In addition to understanding the consequences that changes in climate may have, if we are to act in response to these consequences, we would probably want to know something about how often, or likely, certain consequences may occur in the future. This combination of consequences and likelihood provides a measure of the level of risk that may be associated with fulfilling a given business objective. How significant an organisation then views a certain level of risk will determine whether they feel the need to take action to manage the risk. For example, if a given business operation were affected by a heatwave or drought, which resulted in negative consequences e.g. a financial loss, maybe an organisation would be able to cope with this event, either because they had an insurance policy which covered any losses, or because the business was resilient enough to withstand occasional financial losses. If, however, the losses associated with this kind of event were expected to increase in the future, either because the event became more likely and/or the consequences were greater, would the ability of an organisation to cope remain the same? Would having information on expected or possible changes in the event and associated impacts, motivate action to try and reduce this risk?

This chapter provides an overview of the risk management process, and why it is particularly well suited to dealing with adaptation to climate change (Jones 2001, Willows & Connell 2003, Jones & Preston 2011). Central to being able to make informed adaptation decisions, is having a sound understanding of how various business objectives may be affected and function, in response to changes in future climate (and non-climate) factors. Therefore, the need for causal models of how risk is generated, and how these risks may be assessed is essential. Because the focus of this guidebook is on methods and tools to assess climate risks, we also provide a discussion of what models are, together with an introduction to the associated issue of uncertainty.

3.2 What is risk and the risk management process?

The International Standards Organisation (ISO) 31000:2009 define risk as the:

> "Effect of uncertainty on objectives"

There are a wide range of objectives which operate under conditions of uncertainty, and the impact that this uncertainty has on being able to successfully meet objectives is the focus of the risk management process. These objectives include, strategic objectives such as the reputation of an organisation with its stakeholders, operational objectives such as meeting certain levels of service provision e.g. ensuring a reliable water supply to a city or region, and objectives relating to compliance with legal and regulatory requirements, e.g. chemical concentrations in industrial effluents, or water discharge temperatures. All of these kinds of objectives may be influenced in some way by changes in climate.

Risk is also calculated in various ways, however in this guidebook we adopt the ISO 31000:2009 calculation of risk as being the product of the likelihood of an event and its consequences:

Risk = Likelihood x Consequences

If the likelihood of a given event is assessed as being zero then there is no risk, likewise if there are no consequences from an event then the risk is also zero. Generally, when the likelihood and consequences are higher then the greater the risk, however, things are more complicated than this, as the significance of a given level of risk is what matters to organisations, when deciding whether the risks need treating. This issue will be discussed in more detail in section 3.4.2 on establishing the context for a given risk management task.

The consequences of an event may be positive, which may sometimes be referred to as opportunities; or negative, which may be referred to as threats or vulnerabilities. An organisation may face more than one event which presents a risk to the achievement of objectives, and managing one risk may have implications for the management of other risks, and so it is important to consider risk interactions, this is particularly relevant for reducing the chances of maladaptation. The likelihood of an event can be assessed in qualitative or quantitative terms. These issues are explained more fully in the sections on establishing the context, and risk assessment (section 3.4.3).

Another way in which risk may be referred to is as the product of hazard and vulnerability (DHA 1992):

Risk = hazard x vulnerability (DHA 1992)

To be clear, the ISO 31000:2009 and DHA (1992) definitions are operationally equivalent (van Oijen *et al*. 2013), just that the ISO definition makes it clear that there may be, and permits the consideration of, any positive consequences. It should be clear from this that in practice vulnerability can be viewed as the same as negative consequences.

In the context of risk and vulnerability it is worth pointing out that in the climate adaptation research arena, a lot of effort has been devoted to investigating the vulnerability of various countries and communities to climate change, to the extent that it has become a widely applied method (BMVBS 2011, Malone & Engle 2011, Hinkel 2011).

This guidebook does not explicitly adopt a vulnerability approach to adaptation however, preferring instead the more comprehensive approach of risk management, as we consider this is better suited to our purposes and aims of helping people make sense of, and progress with, adaptation in the real world. Box 3.1 provides some more details on the use of vulnerability and risk assessments, and why we adopt the risk framing in this guidebook.

Regardless whether the risks that a given organisation may face have positive or negative consequences, if we are to be able to adapt then it would be a good idea to have a coherent mechanism through which these consequences can be managed, and the risk management process provides such a mechanism. The ISO 31000:2009, define the risk management process as the:

> "*Systematic application of management policies, procedures, and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring, and reviewing risk*" (ISO 31000:2009)

The various activities involved in the risk management process, and their inter-connections are shown schematically in figure 3.1. It should be pointed out that while the schema in figure 3.1 presents a linear process, the risk management process is not necessarily linear, and various stages can be combined, and revisited, before moving on to subsequent stages.

3.3 What are the benefits of a risk management approach?

There are various reasons as to why adopting a risk management framework to address adaptation to climate change is attractive and powerful, these include (Adapted from ISO 31000:2009, and Jones & Preston 2011):

- **Communication and consultation is integral**: key to developing effective solutions is establishing the proper context for identifying risks, having sound causal models of how a system functions, and identifying and being able to implement adaptation strategies. All these activities demand that there is effective communication and consultation with a range of people, to ensure you have the right people on board in gaining knowledge and understanding, formulating and asking the "right" questions, and identifying practical adaptation strategies and potential for maladaptation. Moreover, raising awareness of climate risks through adequate reporting mechanisms is also a necessity, and the risk management framework provides this.
- **It is all about uncertainty**: adaptation to climate change is characterised as operating under deep uncertainty, in relation to the future development of climate and socio-economic systems, and what this may mean for a given organisation. A risk management framework involves explicit consideration of uncertainty in climate risks, their likelihood and consequences.

- **It is solution focused**: adaptation is about taking action in the real world, reducing threats and seizing opportunities presented by climate change. This means finding and implementing effective solutions. The risk treatment stage in the risk management process makes this focus on finding solutions explicit. Moreover, in relating the level of risk determined by the risk analysis, to what is significant for an organisation, a rational basis is provided on which to stimulate action. It is worth stating that this is not enough to stimulate action, management and board level buy-in will be key. However, it may help, at least get the ball rolling, in integrating climate risks into an organisation's risk management framework.
- **It is a well-established method:** risk management is not new, and many businesses and organisations will already have risk management strategies in place. As such, climate risks can be incorporated into existing mechanisms, rather than requiring new mechanisms to be implemented. This familiarity can aid the uptake and mainstreaming of adaptation into all relevant business activities, and can increase the potential for considering climate as an additional factor, in managing an organisation's risks.
- **It is an iterative process**: adaptation takes place in a dynamic environment where external and internal factors change over time, there are deep uncertainties, and new information is developed which may be brought to bear in informing decision making. As such, adaptation is a continuous social process, and the risk management framework provides an iterative framework well suited to this environment.
- **It is flexible**: a range of different methods (requiring different levels of expertise, time and resources) may be applied to the discovery and generation of information in relation to climate impacts, and considering and planning adaptation strategies. Thus, the risk management process can be tailored to the information needs, resources, and level of detail required to adequately analyse a particular adaptation problem.
- **Facilitates a learning environment**: while a range of different methods can be applied in carrying out a risk assessment, it is the case, that the very act of committing to a process of considering how changes in climate may impact on business objectives, can provide an environment in which much learning about how an organisation operates is obtained. In addition, where the adaptation problem involves a range of stakeholders with different values and perspectives, the process provides a forum in which these issues can be discussed, networks built, knowledge shared and contested, thus facilitating social learning (Hinkel *et al*. 2010). The process will also likely generate learning about the key factors in engaging with stakeholders, and establishing mutually agreeable adaptation strategies.

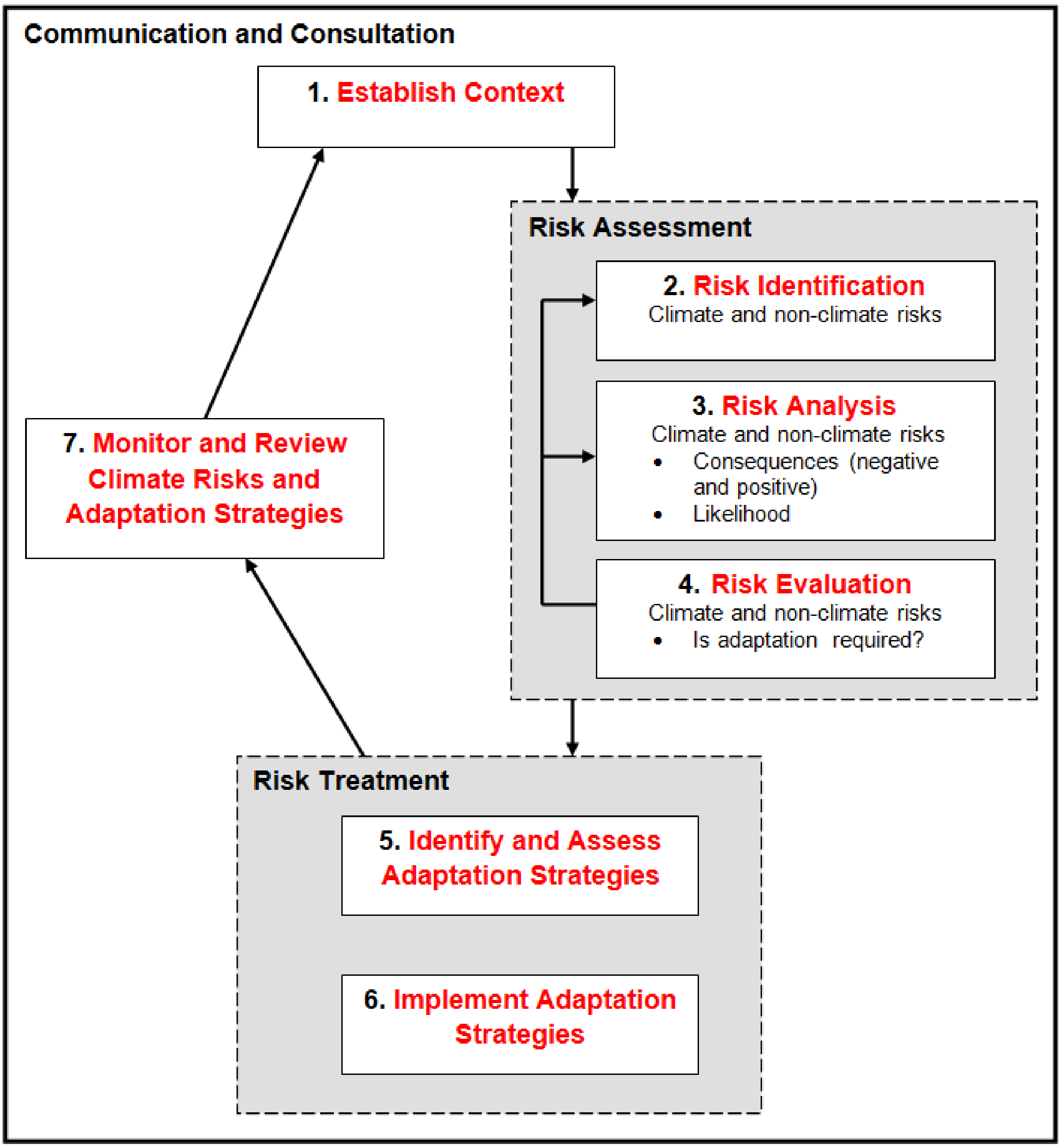


Figure 3.1 A schematic of adaptation as a process of risk management, showing the various stages involved in the risk management process and their interactions, as applied to climate change adaptation. Stages 3 and 5 of this process is where the main focus of this guidebook is placed. The risk management process may not proceed in a linear process from step 1 through 7, and in practice steps 3 and 5 may be performed in combination. *Source*: Adapted from the ISO 31000:2009.

Box 3.1 Risk and vulnerability

The definition of vulnerability that we adopt in this guidebook is that from the IPCC SREX report (IPCC 2012), whereby vulnerability is the "*propensity or predisposition to be adversely affected"*. This propensity to be adversely affected can be investigated under a risk framework as the effect of uncertainty on the successful achievement of objectives, because if the objectives are not successfully achieved there will likely be adverse affects or negative consequences.

There are however, different definitions of vulnerability, and one that has received a lot of focus in adaptation research is that from the IPCC (2007b) which defines vulnerability as: "…*the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity*."

This definition has been used widely in the research arena to perform vulnerability assessments, but it is not explicitly adopted in this guidebook. Moreover, we adopt a risk approach to adaptation in practice, for the following reasons:

1. Risk is a more inclusive and comprehensive framework within which the positive as well as the negative consequences of climate change can be incorporated. Vulnerability focuses only on the negative consequences, and is part of risk.
2. A risk approach provides a means within which uncertainty can be dealt with explicitly. While this is not impossible with a vulnerability approach, it is not explicitly part of its methodology.
3. Risk is solution focused which fits with what adaptation actually is i.e. about taking action. A vulnerability assessment typically doesn't provide as much scope for motivating or seeking solutions, as there is no indication of how big a problem it may be, because we learn nothing about the possible likelihood of occurrence. The use of causal models in risk assessments when done properly, should consider all the relevant factors that lead to the generation of risk, this means consideration of both the climate and non-climate factors, relevant to a given adaptation problem.
4. Risk is an inherently bottom-up approach in the sense that it focuses or structures an adaptation problem around a given objective that an organisation may have. Various methods and tools can then be applied to try and generate an evidence base to analyse the effect of changes in future conditions (climate and non-climate), on the achievement of these objectives.

3.4 Stages of the risk management process

The various stages of the risk management process are now described with focus on the key issues involved at each stage, and the implications for adaptation. While these stages are described in isolation, it is again important to state that in practice a number of these stages may be addressed simultaneously.

3.4.1 Communication and consultation

Effective communication and wide ranging consultation is a continuous aspect and integral part of the whole risk management framework. This means formulating appropriate questions that relate to key business objectives, knowing what these objectives are, and being able to identify a wide range of risks that might impact upon these objectives. Furthermore, when developing causal models of how risk is generated, one needs to be able to call upon all relevant expertise that may exist both within and outside an organisation, in order to have the best possible chance of developing sound system understanding. The same is true when considering potential adaptation strategies, and seeking to implement them, as stakeholder buy-in will almost certainly be necessary. So an effective communication strategy that involves and actively seeks stakeholder participation from the outset is advisable, though this will depend on the specific context of a given adaptation problem. Also, it is crucial that the results of any analyses in relation to adaptation planning are carefully documented and communicated to all relevant parties. Moreover, the implications of any analyses need to be appropriately discussed, the various sources of uncertainty acknowledged, and the level of confidence associated with any analysis reported. In doing so, the actual meaning and implications of the analysis for informing adaptation decision making should be made clear.

3.4.2 Establish the context

Establishing the proper and relevant context for the risk management process is central to the overall success of the process. Stated simply, unless the right questions - properly framed and scoped - are being asked, the value and effectiveness of the later analytical stages will be undermined, and the likelihood of successful risk treatment and adaptation reduced, and may possibly increase the potential for maladaptation.

Important questions to ask when establishing the context, is first of all to determine what is the aim of the exercise, would you simply like to get a feel for how your organisation may be affected by changes in climate in order to raise awareness of climate change, or do you have a specific question or risk, which you know is sensitive to changes in climate. In other words, depending on the complexity of the question or level of detail that may be involved, a number of questions will be important to answer at this stage, these might include:

1. What is the risk or risks that we would like to analyse?
2. Who or what is at risk? Specify the business objectives.
3. What are we actually trying to find out? Or what is the aim of the exercise? Do you need an exact answer e.g. risk will increase or decrease by 15% in 30 years' time, or would simply obtaining a feel for the direction of travel e.g. will the risk increase or decrease in the future, suffice to motivate action? The answer to this question will inform the selection of a suitable method or tool to use to carry out the analysis.
4. What is an appropriate method for answering the aim of the exercise, given the available resources for the analysis? Are we making things too complicated? How will the consequences and likelihood be measured or assessed?
5. What are the key climate and non-climate factors relevant to a given risk?
6. Over what kind of time horizon do we want to consider the risks? This will depend on the planning horizon and decision lead time, and scope for flexibility in adaptation. For example, for a large infrastructure project e.g. a new energy plant or bridge, relevant risks may be analysed over the next century.

7. What are the risk criteria? What level of risk is deemed acceptable, or at what level of risk would we take action to treat the risks? What is our attitude to risk?
8. What are our options for treating the risk(s)?
9. Do we need to involve internal and external stakeholders? Who are the relevant stakeholders? This is a critical question to ask, as it should help ensure that the best possible chance is given to understanding the full scope of the problem that is being addressed, and that the issues that are important to stakeholders are made known and considered.
10. How do these climate risks fit in with or relate to other business priorities or activities?

Having established the context all involved parties (or actors) should be able to answer the question why they are setting out on the task of risk management, and what they are trying to achieve. Irrespective of the motivation for risk management, it cannot be emphasised enough how crucial this stage in the overall process is.

3.4.3 Risk assessment

All risk assessment needs some kind of causal model that links the changes in climate and non-climate factors to the way in which risks are generated (Fenton & Neil 2012). These models can vary from conceptual to numerical models, and this issue is discussed in detail in section 3.5. Risk assessment consists of three stages, whereby risks are identified, analysed, and evaluated. These three stages are described below.

3.4.3.1 Risk identification

The first stage of the risk assessment phase is that of risk identification, which consists of finding, identifying and describing risks. This stage involves identifying risk sources, areas of impacts, and their causes and potential consequences. This stage should also include consideration of any possible knock on effects or dependencies between risks and consequences, as this will be of importance later when considering risk treatment and adaptation options. Key to this phase is being able to develop or identify causal relationships between risk sources and consequences.

Risk identification could involve a comprehensive assessment of all climate risks that an organisation faces, or it could be identifying key risk sources that are relevant to one specific risk, which would go towards developing a causal model, or help in the selection of a causal model, to help analyse the risks. Causal models are discussed in more detail in section 3.5.

It may not be possible to identify all risk sources and consequences however. Nevertheless, it is important that this process is as comprehensive as possible, for each particular adaptation problem. Clearly, communication and consultation with relevant stakeholders will be of major importance in this stage.

This stage of the risk assessment can use a range of different methods to generate this information, including organisational experience of business activities where threats and opportunities that could change in magnitude and/or frequency under climate change are garnered via interviews, workshops, or surveys. Analysis of observations of past climate and weather events and company records that led to a given risk, also offers a potentially powerful source of information. Literature reviews, meta-analyses and professional and industry body literature, summarising the kind of impacts that may be likely in a given sector, could form the basis of a preliminary stage of risk identification.

3.4.3.2 Risk analysis

Having identified risks, the next stage is to generate information upon which the various risks can be analysed and understood. This involves considering the causes and sources of risk, determining their negative and positive consequences, and their likelihood. The combination of the consequences and likelihood determines the level or significance of the risk e.g. high, medium, low. It is generally a good idea to employ a range of different methods for generating the kind of information needed for analysing consequences and likelihood of events.

A number of methods of varying complexity exist, upon which the information needed for risk analysis can be generated, and these are described in detail in chapter 4. The sophistication of the approach taken will depend upon a number of factors, including the size and nature of the risk(s) or adaptation problem, the available resources, expertise, availability of information and data. It may, for example, make sense to adopt a tiered approach to risk analysis, whereby a preliminary risk screening step is performed, leading to a more rapid analysis of the risks, which may then lead to further allocation of resources to permit more detailed investigation of the more significant risks (consistent with the risk criteria), identified on the basis of the risk screening. The available methods range from qualitative analysis of existing information e.g. a survey of available scientific literature on possible changes in climate, and advice from professional bodies, to fully quantitative analysis based on climate impact modelling (where suitable and applicable models exist).

Regardless of the approach taken to generate the information upon which consequence and likelihood is determined, it is important that all analyses provide statements on and consideration of the sources of uncertainty, together with any caveats associated with the methods used to generate the information, and thus the level of confidence that may be associated with the analysis of consequences and likelihood. Assigning a level of confidence is also sometimes referred to as a certainty assessment (WBGU 1998). This issue is discussed in more detail in section 3.5.2.3.

In order to provide a systematic way of summarising, comparing and prioritising risks, the results of a risk analysis are often classified according to an ordinal scale e.g. a value from 1-5, or low, medium, high, and is presented in the form of a heat-map and/or a risk profile. A typical example of a heat-map is shown in figure 3.2, while an example of a risk profile is shown in table 3.1.

These heat maps provide a useful way in which to summarise risks, but the decision of whether or not a given risk needs treating is not simply based on these heat maps or risk profiles, but rather a process of evaluation of what the implications of the risk analysis are, and how the determined level of risk aligns with an organisation's risk attitude.

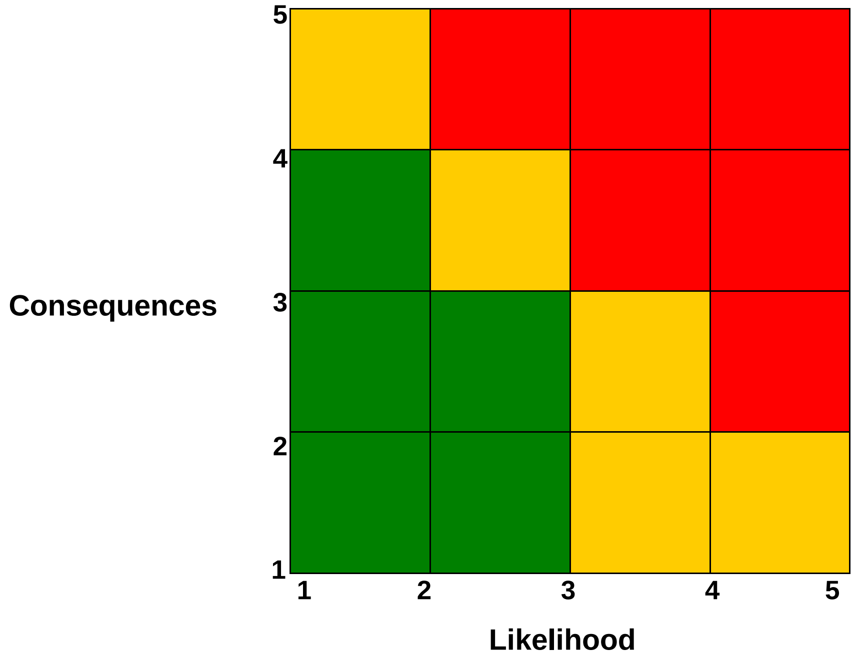


Figure 3.2 An example of a typical heat map, on which the ratings for likelihood and consequences for a given risk or risks could be plotted. Risks appearing in red grid squares would theoretically represent the immediate need for risk treatment, amber squares those where more information or a better understanding of the generation of risk is required, and should be monitored for risk treatment, and green grid squares risks which do not require treatment (adaptation), but should nevertheless be monitored.

Table 3.1 An example of a hypothetical risk profile.

Risk type	Description	Likelihood	Consequences	Priority
Operational	Supply chain disruption	3	5	1
Operational	Lack of cooling water resulting in productivity losses	2	4	2

3.4.3.3 Risk evaluation

Having analysed risks, the next stage is to evaluate what, if any, action is required, or in other words, do we need to adapt? Do I need to take action, and how soon might I need to do so? This decision will most likely not be taken solely on the basis of the risk analysis, but will also likely depend on how the risks relate to other priorities within an organisation, its legal and regulatory requirements, and available resources for taking action. The results of the risk analysis will simply inform the decision making process within an organisation.

The evaluation stage informs the risk treatment stage, and the evaluation involves comparing the results of the risk analysis and the level of risk, against the risk or decision criteria determined at the outset of the process when establishing the context for the risk management process. Whether these risks are evaluated as being significant however, is not simply a combination of the two components, whereby high consequences and likelihood means a large or significant risk. For example, on the basis of a risk analysis a particular event may be assigned a low likelihood, but have very significant consequences if it did happen. An organisation may decide that this risk is too great for them to bear, given their risk attitude, and decide to treat it, or at least to explore ways in which it could be treated. This point serves to highlight that the results of an analysis need to be carefully analysed, interpreted and evaluated. Indeed, the results of a risk analysis can be used to make a decision that more information is needed, and that more research or resources should be devoted to the priority risks, and may even lead to different questions being asked. It is also possible that the results of a risk analysis lead to the identification of new risks (Lempert 2012).

3.4.4 Risk treatment

Having evaluated whether and which risks need treating, risk treatment consists of a two-stage process of identifying and assessing adaptation options, and then implementing the selected option(s). We focus here on the first two aspects of the first stage of risk treatment, identifying and assessing adaptation options. We provide no detailed discussion of the various issues involved in the implementation of adaptation strategies, as there is still a lot of knowledge and experience that needs to be gained in understanding factors which enable organisations to make progress in actively implementing adaptation strategies (Wilby & Vaughan 2011, Moser & Boykoff 2013). Chief among these factors is providing a forum and space for social learning (Hinkel *et al*. 2010, Yuen *et al*. 2013).

Detailed consideration of implementation issues is not, however, the focus of this guidebook, and it is also the case that the process of carrying out a risk assessment can itself provide, or at least initiate, this process of social learning, almost as a by-product (Yuen *et al*. 2013). The PROVIA (2013) adaptation guidance provides some useful discussion of adaptation implementation issues.

3.4.4.1 Identifying adaptation strategies

Having determined the risks that need treating, possibilities for reducing threats and seizing any opportunities that climate change may present, involves being able to identify feasible adaptation strategies. The identification of possible strategies or actions can proceed according to consulting generic or existing strategies which have been researched as possible suitable candidates, and these can be found relatively easily in various sources on the web (see chapter 6). However, it is the case that a lot of the identified adaptation strategies are simply possibilities, the question of how realistic, effective or desirable they are needs to be investigated within the specific context of a given organisations' risks, attitude to risk, availability of resources, and so on. In practice, it may also be the case that having undertaken a risk assessment, there emerge some very clear practical actions that could be implemented relatively simply.

Adaptation strategies for treating risks can be classified according to their mode of operation. These include (adapted from the ISO 31000:2009):

- Avoiding the risk entirely by ceasing certain operations e.g. relocating a factory or distribution centre.
- Taking or increasing the risk to pursue an opportunity.
- Removing the risk source.
- Reducing the likelihood and/or consequences e.g. building more water storage capacity, or public awareness campaigns to use water more conservatively.
- Transferring the risk e.g. through an insurance policy.
- Do nothing i.e. based on the results of an analysis a decision may be made that a given risk can be accepted.

3.4.4.2 Assessing adaptation strategies

Having identified a candidate list of feasible adaptation strategies, the task then is to be able to have some kind of rational basis for choosing between the different options. There are various methods which may be used to do this, depending on the kind of adaptation strategy that is sought, and possibly constraining factors such as organisational culture and fitting in with existing methods and practices. These methods are discussed in detail in chapter 5.

Choosing between different adaptation strategies can be determined according to their relative performance against various criteria e.g. cost, efficacy, equity, stakeholder acceptance. It is also important to state that adequate consideration should be given to the possible knock-on effects that a given strategy may have, such that the potential for maladaptation can be highlighted or detected, and thus avoided.

In order to be able to assess the performance of the different adaptation strategies, we need to be able to link the action of the strategy to the functioning of a given system. This clearly needs to be built into the development of the causal models, be they qualitative or quantitative.

Regardless of the method used to ultimately choose between adaptation strategies, it is very important that the various options should be assessed over as wide a range of possible futures as possible (determined by climate and non-climate factors). The importance of this issue is discussed in more detail in chapter 5.

It is also important to acknowledge that while adaptation strategies may be able to reduce the risk of certain events, they may not be able to eliminate the risks entirely, and as such, plans should be made for dealing with any residual risk.

Again, it should also be clear that deciding which strategies to implement will almost inevitably be determined by more informal considerations relating to the general business decision context and competing priorities.

3.4.4.3 Implement adaptation options

Having determined the strategy or strategies deemed to be most or more desirable, these options then need to be implemented. It may well be the case that a range of different actions are considered and implemented, and this is generally thought to be good practice.

This may be combined with a particular approach to adaptation known as adaptation pathways (Haasnoot *et al*. 2013), whereby, different strategies can be implemented, based on the performance of existing ones, and in the light of new information, and system learning. In other words, as is deemed necessary to obtain an acceptable level of risk.

3.4.5 Monitor and review climate risks and adaptation strategies

After implementation of adaptation strategies it is important that systems are either already in place, or put in place, which will allow for the measuring and monitoring of their performance. It is also important that the various risks identified are monitored and periodically reviewed, either in the light of new information, changes in key factors that determine the functioning of a given system, or as part of a periodic organisational risk management review.

3.5 Models and uncertainty in risk assessment

Increasing the chances for successful adaptation requires a sound understanding of how a given system functions, in response to the key driving variables (climate and non-climate) which may generate a risk for an organisation. This system understanding needs to be represented in the form of a causal model which establishes the relationships and inter-relationships between these variables, and how risks are generated, and thus how we may intervene with well-chosen adaptation actions to minimise threats and maximise opportunities (Fenton & Neil 2012).

3.5.1 Using models: what is a model?

A model may be defined as an abstraction or simplification of how a real world system works. Because models are abstractions of reality, they can never be perfect, but they can be used to make predictions and learn about how the real world functions. As such, models offer great value as heuristic and prognostic tools, enabling us to gain insight into how a system may respond, ask "what if" questions, and enable consideration of future possible worlds or states (Oreskes *et al*. 1994, Walker *et al*. 2013).

In order to analyse climate risks and their interactions with other factors, we need a causal model. These can be relatively simple qualitative conceptual models to highly complex quantitative numerical models (Jones 2001, Fenton & Neil 2012). A conceptual model is a framework or representation of the causal relationships between the various factors that generate risk. Figure A2.2 in appendix 2 provides an example of a conceptual model. Quantitative numerical models also use these causal relationships but represent the processes and relationships in numerical terms. In this guidebook, these kinds of models are referred to as climate impact models, and are discussed in section 4.5.1.

It is important to state that there will be many adaptation problems and issues that are so complex and data poor, that it may not be possible to develop a numerical model of the way in which risk is generated for a given system. As such, a qualitative conceptual approach is needed, and thus it is necessary to generate conceptual models whereby we think through the way in which possible changes in climate may impact a system, through brainstorming sessions, workshops, and logical reasoning. As such, learning and developing understanding of how a given system functions will rely on an organisation's collective experience and knowledge, and insights from employees. This information will play a crucial role in all risk assessments, and should not be viewed as containing little value, there is a lot of value in this, and any risk assessment – regardless of the range of applicable tools and methods – should be grounded in this kind of learning and context.

Moreover, using numerical models can often be a very resource intensive approach, particularly if a number of climate model simulations are to be investigated. This need not be the case however, but careful consideration should be given to the level of detail that is needed in order to answer the kinds of adaptation questions or problems that you have, and thus using numerical models may only be deemed necessary for particularly significant risks.

In developing causal models to help understand the way in which risk is generated, and thus how climate risks may change in the future, it is also necessary to build in the possibility for simulating the effects of adaptation actions into the models, so that their efficacy can be simulated. Using models to help us understand how a system functions does not however provide the answer or solution to our adaptation problems. Rather, they provide information, which may be used to inform a decision making process about which climate risks need treating. The key aspect in the use of models is always the way in which the analysis is carried out, and the implications that are drawn about the way in which a given system functions. A related aspect here is the fact that all models will produce information which is inherently uncertain, a topic to which we now turn.

3.5.2 Understanding uncertainty

This section provides background information on what uncertainty is, why it exists, what the different sources of uncertainty in adaptation planning are, and how we must learn to embrace uncertainty as a fact of life in adaptation decision making. It is essential when making use of different sources of information to help inform adaptation planning and decision making processes, that adequate consideration is given to the issue of uncertainty, and the implications it may have for the development of adaptation strategies (CCSP 2009, Morgan & Mellon 2011). This issue is discussed in detail in chapter 5. This current section is intended to provide a foundation to the topic.

3.5.2.1 What is uncertainty?

Uncertainty expresses our inability to be sure of the outcome of a given event, particularly in relation to its magnitude and timing (Walker *et al*. 2003). Everyday examples of uncertainty include, for example, the outcomes of sporting events, or the punctuality of public transportation, or the time it takes you to arrive at a given destination in a car. If we consider the car example, let us suppose that you have a very important business meeting, for which you plan to travel by car. This plan will take place under uncertainty. There are various factors e.g. a traffic jam, a car accident, a flat tyre, or a closed road, whose existence as threats to your journey time may be known, but whose occurrence in time and space, we may not be able to predict. However, we do know that the occurrence of these factors would increase our journey time. Given that you wouldn't want to miss or be late for the appointment, you would probably build in some safety margin to the amount of time you allow for making this journey, to account for the occurrence of these uncertain events. This is particularly the case if we are driving in a foreign country or city, where we may have less experience, and thus less knowledge, of the local transport system and road network. The point here is that even if we may not always understand it as such, we deal with uncertainty in many different activities, every day.

3.5.2.2 Why does uncertainty exist?

Uncertainty exists because we do not know, or have an incomplete understanding of how a given system works. We may be aware of certain processes that are missing from the models, but we are simply not able to represent them, either because it is impractical computationally, or we do not understand the processes well enough. These are referred to as known unknowns. There are also, unknown unknowns, these are processes or mechanisms, about whose existence and function we are simply not aware – we do not know, and are thus ignorant. As such, they cannot be represented in models. There are some examples e.g. rolling a dice, where we do know all the possible outcomes. In complex systems, such as the Earth system, we are simply not able to define all possible outcomes, as we do not understand the entirety of how the Earth system functions, and as such we are uncertain about possible future outcomes.

Known unknowns in a climate context, could be, for example, the modelling of methane degassing from the Arctic. We are aware of this process, but we do not fully understand how it operates, and how to represent it in a model, so this potentially important process is not included in current state-of-the-art climate models.

The effect of these two issues should be borne in mind when dealing with any modelled information, and relates to the certainty or level of confidence we may have in the risk analysis. It may be that as we learn more there are certain key mechanisms which could have a big impact on system functioning, and thus possibly provide the potential for surprises i.e. situations that a model does not or cannot simulate (CCSP 2009).

It is also the case that in modelling there is a certain element of irreducible uncertainty that will always be present, due to chance. We may however, be able to place some bounds on the range of uncertainty that may be expected. As such, uncertainty is a fact of life, and something which, in the context of adaptation planning, we should learn to accept and embrace, and think of smart ways in which we can reduce the potential impact of uncertainty on our adaptation strategies.

3.5.2.3 Reporting, documenting and communicating uncertainty

The risk analysis stage of risk management provides an estimate of the likelihood of a given event and its consequences. It is however also necessary to provide a statement on the level of confidence that may be had in the evidence, upon which the assessment of the likelihood and consequences is based. This assignment of confidence in the assessment is referred to as the certainty of assessment (WBGU 1998).

There are various ways in which the quality of the evidence base may be assessed and chapter 6 provides some links to other methods that may be used to assess the certainty of assessment. One approach is that adopted by the IPCC in developing their fifth assessment report (AR5) (Mastrandrea *et al*. 2010b). The level of confidence that may be had in a given assessment of likelihood and consequences, can be determined based on the amount of evidence and the level of agreement that exists, as shown in figure 3.3. This assessment can be based on the results of literature reviews, model analyses, and/or internal organisational agreement on the level of confidence in risk estimates, depending on how the risk analysis was carried out.

When reporting the results of the risk analysis a traceable account of supporting evidence should also be produced, from which assessments of uncertainty and confidence can be checked, and updated.

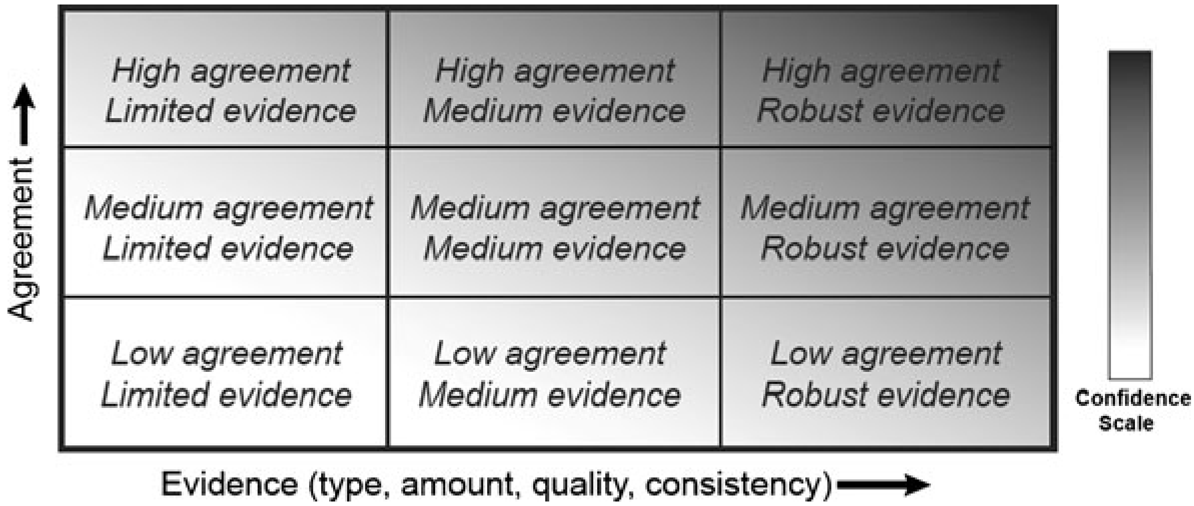


Figure 3.3 The confidence matrix employed by the IPCC AR5. *Source*: IPCC (2012).

3.5.2.4 Uncertainty is information so use it

Uncertainty is often seen as a barrier to action in adaptation. This may be because there are too many uncertain possibilities that people cannot make sense of it all, and feel overwhelmed by it, or that because of the uncertainty, they consider that the best approach would be to carry on as normal, and react to climate risks as they appear. This phenomenon has been referred to as the “uncertainty fallacy” (Lemos & Rood 2010), whereby people consider that they need to have more certainty about possible outcomes before acting. While it may be so that over time research may be able to reduce uncertainties, this is by no means certain, and in any case, the fact of the matter is that there will almost always be large uncertainties associated with adaptation decision making, and it simply needs to be embraced, understood, and managed appropriately.

Moreover, decisions may need to be made now, and thus there is no time to wait for a reduction in uncertainty, which may in any case not arrive. Because we are uncertain about what future we need to adapt to, does not mean that we cannot be confident enough in our knowledge to make decisions to manage climate risks. Perhaps a clear trend is persuasive enough to motivate action, or maybe knowing that a given management strategy may fail under certain conditions is enough motivation to take action. We will never have complete certainty, making adaptation decisions in the face of this uncertainty is still possible. Chapter 5 provides a more detailed discussion of this issue, and how adaptation strategies can be developed in the face of uncertainty.

3.6 Chapter summary

This chapter has shown that:

- Risk management provides an attractive and powerful framework within which to deal with climate risks and approach adaptation.
- Risk arises through a causal chain of events, and this chain is represented in a causal model. Good risk assessment and management requires a sound understanding of the relationships and interrelationships that lead to risk(s).
- The use of models which represent our understanding of how a given system responds to changes in climate and non-climate factors, and how risk is generated, is an essential part of adaptation planning.
- A lot of this system understanding will rely on organisational knowledge and learning, and thus effective communication, and organisation buy-in to adaptation.

4 Methods and Tools for Climate Risk Assessment

Chapter Highlights

- Introduces a range of methods and tools that may be used to carry out a climate risk assessment, and thus assist adaptation planning.
- Provides a wide ranging discussion of issues involved in making use of climate information.
- Provides a means of assessing the different methods and tools, as to their applicability and suitability for use in adaptation planning.

4.1 Introduction

Understanding how a given system responds to climate and non-climate factors is central to successful adaptation planning. In order to assess how business objectives may be affected by changes in climate, and other non-climate factors, and thus understand how big a threat or opportunity may exist, how urgent the task may be, and duly decide whether we need to adapt and how, then we clearly need some methods and tools with which we can generate an evidence base, to start answering these kinds of questions. The better we understand how our system functions, the more guidance we have on which factors could be acted upon in order to manage the risk, and thus aid the search for, and development of, successful adaptation strategies. This chapter provides a discussion of some of the main methods and tools that can be used in support of assessing climate risks. The choice as to which method or tool to use will depend on a number of factors, chief among which will be the size and complexity of the adaptation problem (which may mean a complex or more simple method is pursued), the available resources (time, financial, expertise), and the nature of the uncertainty involved in the problem (ISO 31010:2009).

4.2 Methods and tools for climate risk assessment

Whilst it should be clear that the kinds of climate risks that organisations face are generated by both climate and non-climate factors, there is a focus in this chapter, on describing those methods and tools that may be used to investigate what the impact of changes in climate may have on a given system. It is important to state however, that this isn't an exclusive focus, for example, the use of scenarios for forward planning can be applied to both climate and non-climate factors. Moreover, many of the methods can make use of and may even in some way depend on the use of socio-economic, and socio-political data, as is illustrated by case study one in Appendix 2.

A wide range of statistical data of past changes in socio-economic variables, as well as some projections of future changes e.g. population change, are available from the Statistisches Bundesamt (DeStatis) for changes in Germany, and for Europe and the World, from the European Union (Eurostat), and World Bank, and the Shared Socio-economic Pathways (SSPs) database, see chapter 6 for more detail on these data sets.

4.3 Scenarios and scenario planning

Adapting to climate change and variability essentially means developing plans or strategies that are able to reduce the negative consequences, and maximise any positive consequences, that may occur. This clearly means that we need to think about the future and how a given system may function or respond under future conditions of changed climate and non-climate factors. It is not possible, however, to predict the future with certainty, and as such there is uncertainty as to what the future may hold. The use of scenarios is a way of dealing with this uncertainty. The value of scenarios as a forward planning tool is to consider the implications that different plausible futures might have for the achievement of business objectives, and thus how an organisation may respond or plan to face uncertain futures. Scenarios are used in various economic sectors, and perhaps one of the most successful examples of the development and use of scenarios is Royal Dutch Shell Plc, who, through the use of scenarios were well prepared to respond to the oil price shock of the 1970s (http://www.shell.com/global/future-energy/scenarios.html). Other examples of scenarios are those developed by the International Energy Agency (IEA) (http://www.iea.org/publications/scenariosandprojections/), the World Business Council for Sustainable Development Vision 2050 (http://www.wbcsd.org/vision2050.aspx), and the IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic *et al*. 2000).

4.3.1 What are scenarios?

Scenarios may be defined as:

> "A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships." IPCC (2007b).

Scenarios are thus, not predictions about how the future will turn out, rather, plausible possibilities or alternatives that may appear. As such, they serve as an aid to critical thinking supporting the development of adaptation strategies that could manage or ensure success under different futures. In other words, they provide a framework for asking the questions: how would our existing strategy work under different future conditions? How might alternative strategies perform under future conditions?

Scenarios may be qualitative or quantitative, and often the two are combined, with a qualitative scenario being used to run a quantitative simulation model under the assumptions contained in the qualitative scenario. For example, global climate models are used to generate quantitative scenarios (or projections), of how a range of different climate variables may change in the future, based on the assumptions in the SRES qualitative scenarios. Qualitative scenarios are normally accompanied by a 'storyline', which provides a narrative description of how a given scenario materialises.

There are three main kinds of scenarios (Rounsevell & Metzger 2010):

- **Exploratory** - which ask "what if?" questions e.g. what if future water demand were to increase by 25% in 20 years time, would our business or organisation be able to meet this demand. Alternatively, what if the number of heatwaves in a given city were to increase in frequency and intensity, what kind of implications might this have for the provision of health services in the city? Would we be able to meet our required level of service? If not, how could we?
- **Normative** - which start with a stated or desired outcome, and then work back through different ways in which this desired outcome may be achieved, e.g. EU policy targets for reducing greenhouse gas emissions by 80-95% compared to 1990 levels by 2050 (http://ec.europa.eu/clima/policies/brief/eu/index_en.htm)
- **Business as usual** – which essentially says that current trends will persist into the future. Clearly, over time the relevance of this kind of scenario may decrease as the world changes. However, they are still of value when trying to think through the relative merits of policies under alternative scenarios, as they provide a baseline or reference against which any alternatives can be compared.

4.3.2 How can scenarios be developed?

Scenarios may be developed in various ways, depending on the particular context of the decision that needs to be informed. They may be developed by teams of experts within an organisation, in collaboration with external experts, and/or stakeholders. Scenarios which are developed with stakeholders are termed participatory scenarios, whereby all parties to a given decision are consulted and involved in the development process (Reed *et al*. 2013). Participatory scenarios are often an essential part in developing adaptation strategies. It may, for example, be necessary to agree with stakeholders what acceptable targets are for the provision or operation of a given service, and also the various strategies that may be necessary to ensure maintaining these targets into the future (Brown *et al*. 2011, 2012, Lempert & Groves 2010).

When developing scenarios, the aim is to capture the main driving forces of factors which are of most importance to understanding a particular decision context. These driving forces may include, for example, trends or plausible changes in population growth, technology, energy use, patterns of consumer behaviour, and use of environmental resources. Because scenarios are used as a tool to support critical thinking about how a given system may function or respond under different plausible futures, typically only a few well-chosen scenarios are developed, which span a wide range of plausibility in the driving forces or trends of development. If too many scenarios were developed it would likely take the focus away from thinking about different adaptation strategies, and instead focus more on trying to understand the differences between scenarios, thus hindering the thought process of how an organisation may respond, which is the main purpose of scenario planning.

Scenarios are typically developed for future time periods from a couple of decades to a century ahead, although there is nothing preventing thinking through or developing scenarios that are focused more on the shorter term e.g. thinking through an organisations' current capacity for responding to climate risks (Vermeulen *et al*. 2013). Scenarios can be developed at a range of spatial scales, from global energy or emissions scenarios, to national, regional and local scenarios of, for example, changes in energy consumption, consumer behaviour, urban growth, and demographic change.

In adaptation planning, the need for developing scenarios will most likely centre around developing scenarios in relation to changes in the non-climate factors, e.g. a 25% increase in water demand over the next 25 years, due to population growth in a given area. The need to develop your own climate scenarios (based on climate models) is likely to be very low, since there are a number of climate scenarios which are available and as such may be used as 'off-the-shelf' products, these may however be 'tailored' for a given organisation. The task then is linking these scenarios which describe different plausible futures, to a model of how a given system functions.

Developing or using scenarios is as much, if not more, about the process, as it is about the scenarios as a product themselves (Rounsevell & Metzger 2010). If scenarios are developed, or deliberated on with a wide range of stakeholders in a participative process, the very act of discussing and considering different potential futures, offers the potential for identifying mutually agreeable strategies, where the different values and perspectives that stakeholders have, may be satisfied and reconciled with meeting business objectives. As such, scenarios as a process, offer much potential for consensus building and social learning, and ultimately may smooth the adaptation decision making process, and likely success of any adaptation strategies or actions. Moreover, this process of considering competing values may reduce the likelihood of pursuing an optimal strategy favoured by one actor, which may mean that agreed strategies are more robust in the face of future changes (chapter 5 provides a more detailed discussion of these issues).

The process of thinking through different plausible scenarios and thinking about strategies that may ensure business success, should increase the resilience of organisations to future change in business conditions, and possibly also to the occurrence of surprises or shocks i.e. events that were never conceived of as being likely to happen e.g. the oil price shock of the 1970's. Another advantage of pursuing a scenario process is that a lot of organisational learning is obtained in addition to the social learning. An organisation may learn how to better communicate internally and externally, who has what kind of expertise, who good contacts are, and what the factors for success are or may be.

Scenarios thus offer a potentially powerful means of supporting adaptation planning, but key to the process will be the accurate identification of the key driving forces, how these are then characterised, and the avoidance of bias in thinking about uncertainties (Reed *et al*. 2013).

4.4 Making use of climate information

4.4.1 What kinds of climate information are there?

Essentially there are two main kinds of climate information, based either on observational data, or modelled data. Observational data are clearly most useful for learning about past and present changes, while model data can be used for both learning about the past and also possible future climates. Using these two sources, it is possible to generate information relating to basic changes in climate variables e.g. surface air temperature, climate indices and extremes e.g. number of days when summer maximum temperature is > 25 degrees C, and to generate climate scenarios. These two sources and the main kinds of information that can be used to assist with climate risk assessment are described below.

Deciding which climate information to use will depend upon the nature of a given adaptation problem, and specifically the associated planning horizon. Clearly, if there is a business decision that needs to be made which is climate sensitive but can be adjusted within a short time period, then using observed data, statistical relationships and trends, or learned experience may be a suitable approach, rather than using modelled data. If however, there is a business decision whose lifetime will extend over a couple of decades or more, and/or has a long planning horizon, then climate models will need to be consulted and incorporated into the planning and decision making process.

4.4.1.1 Uncertainty in climate information

In the context of using climate information to help establish an evidence base to inform adaptation planning, uncertainty stems from two main sources: uncertainty in the observational data – known as measurement uncertainty; and modelled data – known as modelling uncertainty (CCSP 2009). Measurement uncertainty derives from a number of sources, including: our inability to measure phenomena accurately due to instrument error or random noise, the lack of data in a given area or over a given time period, and data sampling issues particularly their temporal and spatial resolution.

Modelling uncertainty also derives from a number of sources, including: the observational or measured data which may be used to construct or parameterise the model (and thus all the sources that relate to the observations relate to the models), incomplete understanding and representation of all the relevant processes in a given system, and basic ignorance about the full suite of processes that operate in a given system.

To illustrate this issue more clearly, the main sources of uncertainty in modelling future climate are summarised in section 4.4.4.6. The main sources of uncertainty in the other methods are dealt with as they are presented in the following sections.

It is important when using any observational or model derived data or information, that users are aware of the various limitations and caveats that may apply. In so doing, the proper meaning of any climate information can be assessed appropriately, and the implications this may have for informing the adaptation decision making process understood. The implications of any modelling limitations for interpretation of results should be clearly detailed and reported, and it may be necessary to consult relevant experts to assist with this task.

4.4.2 Where have we come from and where may we be going?

If we are concerned that some of our business activities and objectives, are or may be sensitive to climate, and we would like to be able to assess future climate risks, it is helpful to know how the climate has affected business operations in the past and/or present, in order to help in understanding how these risks may change in the future. Moreover, if we wish to know how we may be affected by climate change, then we need to be able to measure this change against something - we therefore need to establish a baseline, or reference period, against which changes can be set in context. A baseline or reference period for change should be established with respect to both the climate and socio-economic factors, whose interaction generate risks. If we know how things may change, we can then understand these climate threats and opportunities, and take steps to manage or treat them. The need for a baseline is also essential in being able to compare possible adaptation strategies against current strategies for managing a given risk, and thus aiding the identification of suitable adaptation strategies. In other words, having a baseline enables us to assess the relative performance of, and need for, alternative strategies, in order to manage risks.

4.4.3 Using climate observations

Climate observations can be useful for a range of purposes in adaptation planning. They may be used to:

1. Generate awareness of changes in climate variables that may be of relevance, by examining the climatology of a given area, and may be particularly useful for the investigation of changes in climate extremes or indices. The use of observations or consulting reports where observed changes in climate are reported, may be particularly useful for carrying out a risk screening exercise, where a general feel for the potential size and/or seriousness of a given risk can be obtained.
2. Establish a baseline from which observed and future climate change can be calculated.
3. Assist in the development of statistical models which describe the way in which a given social-ecological system functions.
4. Identify critical thresholds beyond which a particular system enters a risk zone that needs treating. These critical thresholds could be identified on the basis of association between a recorded event and observed climate from national records. Alternatively, it may be the case that organisations keep databases which record the weather conditions associated with events which are of concern to an organisation. If so, exploring these databases to try and identify thresholds or even relationships between a given event of concern and weather conditions, would be a very worthwhile pursuit. These thresholds or relationships could then be investigated for establishing the frequency with which they may occur in the future, in order to provide evidence for making a decision whether or not an adaptation strategy is needed (McColl *et al*. 2012).

4.4.3.1 National observations

In Germany (and other countries around the world), national meteorological and hydrological services will routinely collect and make available for use, observations of a range different climate variables, at varying spatial and temporal resolutions. These data may be purchased from these centres. In Germany, the Deutsche Wettterdienst (DWD) is the national meteorological service, charged with responsibility for collecting, analysing, quality assuring, and archiving observed climate data. Chapter 6 provides a link to the DWD website where more detail on available climate observations can be found.

4.4.3.2 Global observations

If the interests of a given organisation extends to beyond Germany then it will be necessary to contact the local meteorological services for local or high spatial resolution data. In addition, there are various sources of global observed climate data sets, containing a range of different climate variables, for different historical time periods, at different spatial and temporal resolutions, and spatial coverage. Two of the main data sets are those made available by the NASA/GISS in their GISTEMP data set, and the NOAA/NCDC Global Historical Climatology Network. Both these data sets are freely available for commercial application, and links are provided in chapter 6.

4.4.3.3 Suitability for use or fitness for purpose

Depending on the characteristics of the observational data set (e.g. spatial and temporal resolution), and the use or question to which they are applied, they may be more or less useful for their intended purpose. For example, if the task is to generate a climate baseline for a given region or country, an issue to consider will be the density of observational sampling in relation to the heterogeneity of the landscape within a region. If a given observational data set is sparsely sampled over an area of homogeneous relief then the data may be more suitable than if they are sampled sparsely over a more heterogeneous area e.g. with mountain ranges, major lakes, and/or major changes in land cover. To assist in answering such questions about fitness for purpose, it may well be necessary to consult relevant experts.

4.4.4 Simulating future climates

If we want to be able to assess future climate risks, it is necessary to have some idea as to how future climate may change. Our most sophisticated tool for this is to make use of global climate models (GCMs). Additional ways in which information about possible future climates may be obtained is the use of temporal and spatial analogues. It is also possible to simulate or construct future climates using synthetic data. In the following sections we review the main methods and tools that may be used to investigate different possible future climates, and the various issues that are associated with their use and application.

4.4.4.1 What is a global climate model?

A global climate model is a numerical representation of the various processes that take place in the Earth's atmosphere, ocean, cryosphere and land surface. These models are based on well-established physical laws, and observations of physical processes. They simulate for example, incoming and outgoing radiation, cloud formation, atmospheric and ocean circulation, and they also try to simulate the interaction of these various processes (McGuffie & Henderson-Sellers 2005). Global climate models are highly complex, and are extremely computationally demanding, making the use of supercomputing a prerequisite. These models solve these processes mathematically at a series of grid points in the atmosphere and ocean, and across the land surface, and as such have both horizontal and vertical resolution. Because of the complexity, these models are currently only computationally tractable when run at relatively coarse spatial resolutions, on the order of 100-300 kilometres.

4.4.4.2 How is future climate model information generated?

Future changes in climate will largely be determined by the concentration of greenhouse gases (GHGs), and aerosols in the atmosphere, and the changes this leads to in the functioning of the Earth system. Future atmospheric concentrations of GHGs and aerosols will be determined in large part by human activities. If we want to be able to simulate future climates, we therefore need to make some assumptions about the way in which human activities will be organised in the future, and thus produce plausible scenarios of how concentrations of GHGs and aerosols may develop. The IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic *et al*. 2000), represents a major activity which has formed the basis for the generation of a large number of climate model simulations. These scenarios make various assumptions about, for example, global human population development, how our economic affairs and trade will be organised, what technologies we might employ, and the fossil fuel intensity of human activities.

Recently, a new set of emissions scenarios has been developed by the science community to try and address some of the constraints that use of the SRES scenarios placed on the climate simulations. These new scenarios are called the Representative Concentration Pathways (RCPs), and take a different philosophical approach to that of the SRES (Moss *et al*. 2010, van Vuuren *et al*. 2012). Whereas the SRES scenarios assumed a given pathway of socio-economic development would lead to a particular level of emissions, the RCPs do not. Instead, many different development pathways may be consistent with the level of emissions and thus concentrations of GHGs and aerosols, under the RCP scenarios. A new set of socio-economic scenarios has also been developed, called the Shared Socio-Economic Pathways (SSPs), which may be used in conjunction with the RCPs. The background and differences between the SRES and RCPs is described in more detail in Appendix 1.

Using these emissions or concentration scenarios with global climate models, allows future climate scenarios or projections to be made, which are conditional upon the assumptions made in a given emissions scenario. In this way, we can obtain quantitative information on the way in which future climate may evolve.

4.4.4.3 What kind of information can these models generate?

Global climate models can be used to generate information for a few months ahead and these are known as seasonal forecasts; for the next decade - these are known as decadal predictions; or for many decades ahead i.e. 20-100 or more years - these simulations are known as multi-decadal or centennial projections.

To date, most focus in adaptation planning has tended to use multi-decadal projections, which is a function of the relative maturity of this field, and data availability, compared to the seasonal and decadal projections (Vermeulen *et al*. 2013). Seasonal forecasts have been shown to provide useful information in some parts of the world and are used to help people adapt particularly in developing nations (Lizumi *et al*. 2013). Decadal predictions on the other hand also have some skill in predicting certain climate variables and phenomena in certain parts of the world and/or at the global scale, however, these predictions are very much an experimental research area (Meehl *et al*. 2009). As such, despite their appeal in terms of the time horizon for planning, a major amount of progress is needed in this area before they may be suitable for assisting with typical adaptation planning problems (Tollefson 2013).

4.4.4.4 What is the spatial and temporal resolution of the data?

Global climate models, because of their complexity, typically have spatial resolutions on the order of 100-300 kilometres. This coarse spatial resolution is due to the computational expense of representing and solving many mathematical equations at each point in the Earth system grid. As compute power has increased over the years, so too has the spatial resolution of the climate models, and this is shown in figure 4.1. Because of this coarse resolution, the use of GCM data for informing adaptation planning is not always appropriate, and so the GCM data are downscaled, which is described in section 4.4.4.5.

GCMs perform calculations at an approximately 30 minute time step, however, the temporal resolution of the GCM data that is actually available to users, is typically monthly data. Most data that are available are produced for a given time period, for example the 2050s. This time period typically is an average of climate model simulations over a thirty year period. What this means is that for say average June or summer temperature in the 2040s, this is an average over the time period 2030-2059, and the time period is labelled according to the middle decade of the thirty year time period. It is also possible to obtain daily data, from what are known as transient climate simulations. Having access to these data may be necessary if you are interested in investigating the temporal occurrence or earliest (and latest) time, when a given threshold or target of interest is exceeded or reached. Generally, there are more daily data available for regionally downscaled data than GCMs. Chapter 6 provides more information on the availability of regional climate model data sets.

4.4.4.5 Downscaling global climate model data

Global climate model outputs are not particularly well suited to the kinds of questions related to adaptation planning, owing to their coarse spatial resolution. In order to bring the results of global climate models closer into line with the needs of users, the global climate data may be downscaled. There are two main approaches to downscaling climate information to the regional level: dynamical and statistical downscaling (Fowler *et al*. 2007, NKGCF 2010). Dynamical downscaling uses regional climate models, whereas statistical downscaling can proceed via a range of methods, for example regression analysis. A precondition for all downscaling however, is the realistic representation of large scale circulation patterns from the driving GCMs.

4.4.4.6 What are the sources of uncertainty in climate model outputs?

The development of future climate information based on climate model outputs is confronted by three sources of uncertainty, related to: natural variability, uncertainty in the climate response to radiative forcing as represented by the models (model uncertainty in figure 4.2), and greenhouse gas scenario or emissions uncertainty (scenario uncertainty in figure 4.2).

The relative importance of these different sources of uncertainty varies with the time and space scale considered. From figure 4.2 we can see that over time, and from the global to the regional scale, uncertainty increases; for the development of future climate information at seasonal and decadal timescales, natural variability is the main source of uncertainty, whilst at decadal timescales model uncertainty and internal variability dominate, with scenario uncertainty playing a relatively minor role; at multi-decadal to centennial timescales, (emission) scenario uncertainty is the main source of uncertainty.

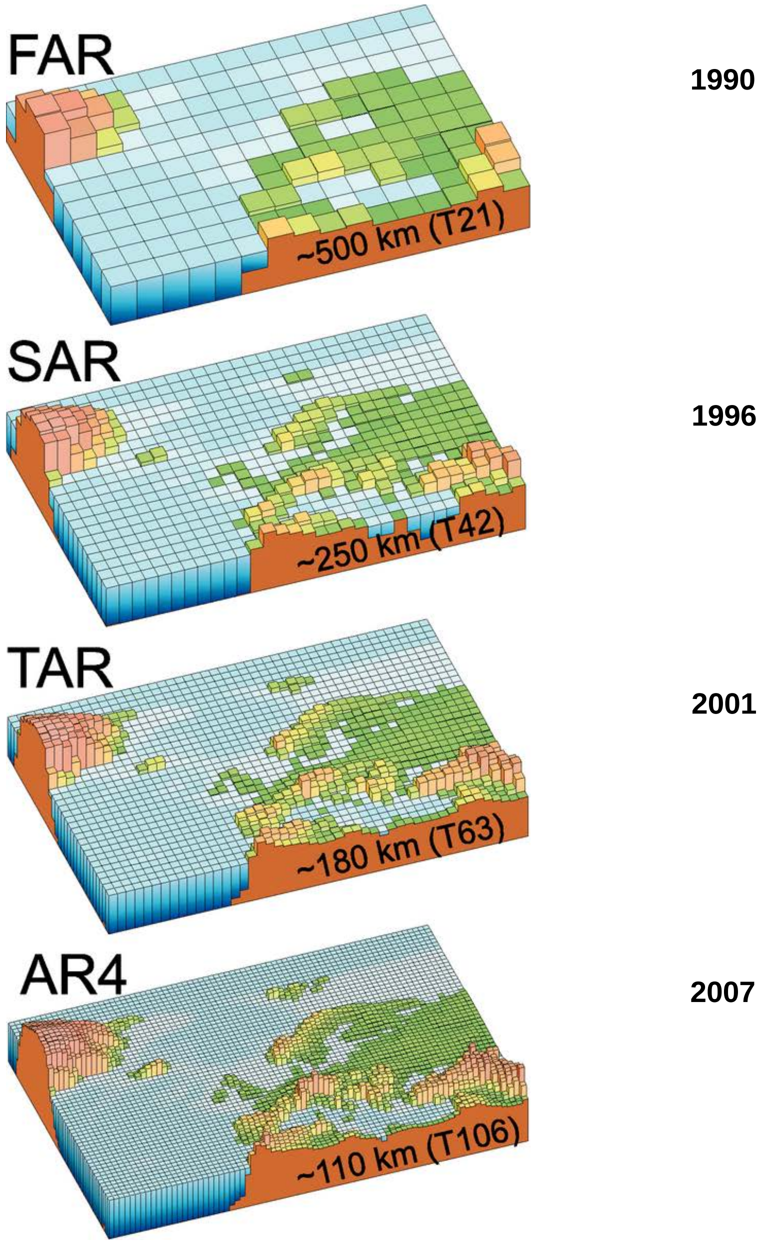


Figure 4.1 Improvements in the spatial resolution of global climate models over time, as represented in the various IPCC Assessment Reports. FAR is the first assessment report (1990), SAR is the second assessment report (1996), TAR is the third assessment report (2001), and AR4 is the fourth assessment report (2007). *Source*: Letreut *et al*. (2007).

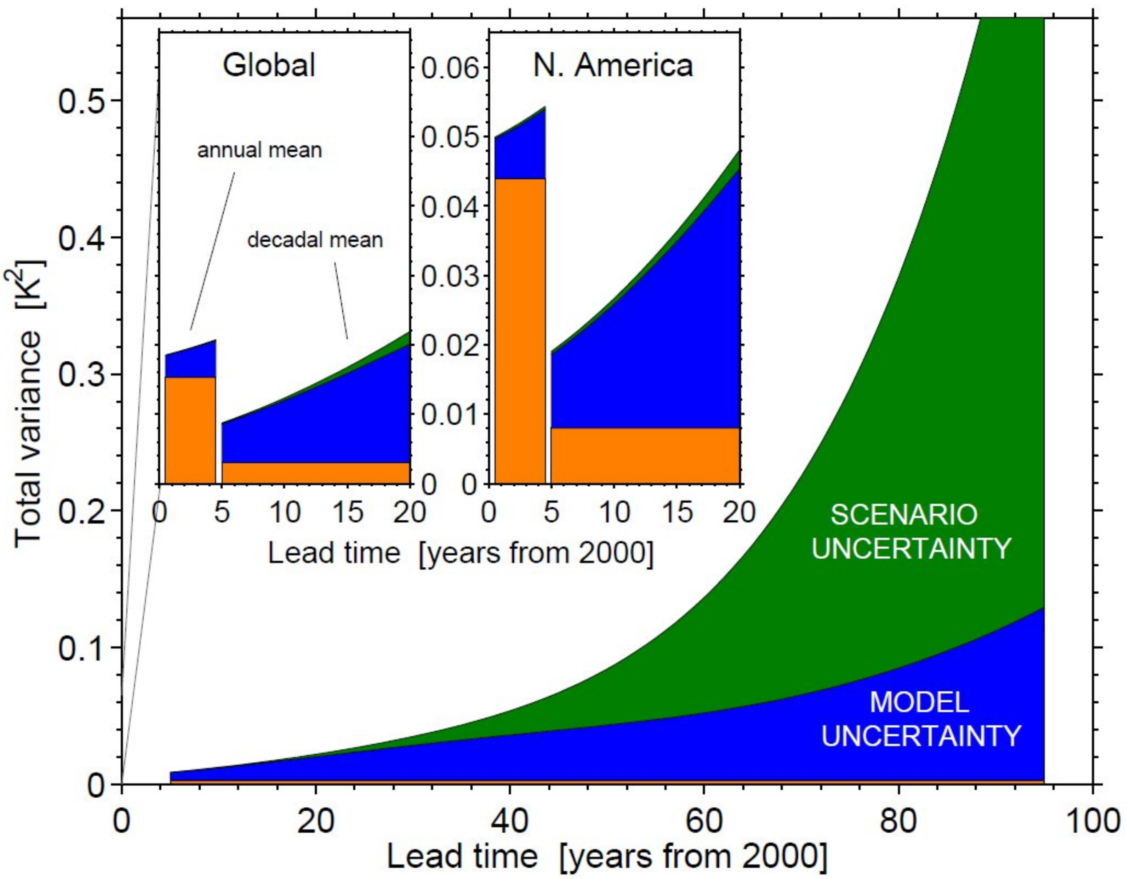


Figure 4.2 Sources of uncertainty in climate models. Orange shading is natural variability. Scenario uncertainty is emissions uncertainty. *Source*: Hawkins and Sutton (2009).

4.4.4.7 Can we quantify this uncertainty?

The most common way in which we may try and quantify uncertainty is through the use of probability. This can mean specifying a percentile range or possible variation to be expected, through to generating full probability density functions (WBGU 1998, CCSP 2009). The way in which we quantify uncertainty, is important for the meaning we may attach to the results of any model or statistical analysis, and thus how this may be used and interpreted in informing the adaptation decision making process. This issue of quantifying uncertainty is relevant to the way in which we may generate information about possible future climates, and has implications for how we may go about developing adaptation strategies. These issues are discussed in detail in chapter 5.

4.4.4.8 How is it possible to deal with this uncertainty?

Given the sources of uncertainty in climate modelling, when generating data that may be used in support of adaptation planning, one would ideally have data available that was generated from multiple different climate models which had each been run multiple times, exploring a very wide range of uncertainty in parameter values. This would also ideally be done for a range of different future emissions or concentration scenarios. Unfortunately, because of the large compute time required to run global climate models, this is generally not practical at the present time.

What are our options then for dealing with this uncertainty in future climate? One approach for which suitable data are currently available, is to make use of what are known as multi-model ensembles (MMEs). Because different international climate modelling centres have different models, and structure them in specific ways, combining simulations from a number of these different models into an ensemble is one way in which uncertainty can be explored in the climate modelling. A multi-model ensemble is then a collection of different climate model simulations obtained from a number of different climate models. This MME approach typically does not explore a lot of variation in uncertain process parameters, with typically only a small number of simulations being performed with each model. Clearly, this represents a sparse sampling of the available parameter space, and uncertainty will likely be underestimated (Stainforth *et al*. 2007).

Another method for dealing with uncertainty is to generate what is known as a perturbed physics ensemble (PPE). In this approach, a single climate model is used, in which a large number of model parameter values are varied across their plausible range of values, and the climate model run for each instance. This approach allows the generation of a large number of model versions, each one being a member of the ensemble. There are however, very few examples of such PPEs being generated and made available to the public. Chapter 6 provides more details on where suitable climate model data sets may be obtained.

4.4.4.9 Can we have confidence in climate model outputs?

The IPCC AR4 report (IPCC 2007d), states that climate models do provide credible quantitative estimates of future climate change, particularly at continental scales and above, and as such we may have confidence in the model projections. This confidence in the model outputs derives from three main sources: 1) the fact that they are based on well-established physical laws, 2) they have been able to reproduce aspects of current climate, and 3) they have been able to reproduce key aspects of past climate and climate changes. This ability of climate models to reproduce past climate is shown in figure 4.3, which compares climate model simulations of global temperature anomaly over the 20th century, to climate observations. The figure shows that when both natural and anthropogenic external forcings are included (figure 4.3a) there is close correspondence between the model and observations. It is important to state that this ability to reproduce past observations with some skill tells us nothing about the future, and as such this is a necessary, but not sufficient criterion, for using the models for future time periods. It is also important to state that there is more confidence in certain climate variables e.g. temperature, than others, e.g. precipitation.

Moreover, there are a number of areas where climate models can be improved in terms of their process representation, for example with regard to cloud formation (Schiermeier 2010). It is also important to keep in mind that any model will have errors, and that the way in which climate model data sets are generated in terms of their experimental design, will mean that a greater or lesser extent of possible uncertainty is explored and quantified. Regardless of experimental design, it is important to avoid over-confidence and consider that no modelling exercise can ever cover all possible climate eventualities, and the potential for surprises is always present (Stainforth *et al*. 2007). This is a major factor to consider when developing adaptation strategies which may be based, at least in part, on an analysis of climate model data. Chapter 5 provides more discussion of these issues, and the implications of uncertainty for adaptation decision making.

4.4.4.10 Where can I find climate model data?

A range of global and regional climate model data are available for use. One of the most comprehensive sources for climate model data, which contains the results of various climate modelling experiments is the IPCC Data Distribution Centre, and the Earth System Grid Federation. Other useful sources of data are ENSEMBLES which provides regional climate model data for Europe, and soon Euro-CORDEX. Chapter 6 provides more information and links to available data sets, and their availability for commercial use.

Also, nationally and regionally there are a range of centres that make climate data available, sometimes in tailored or customised packages. Interested users should consult chapter 6 for more details.

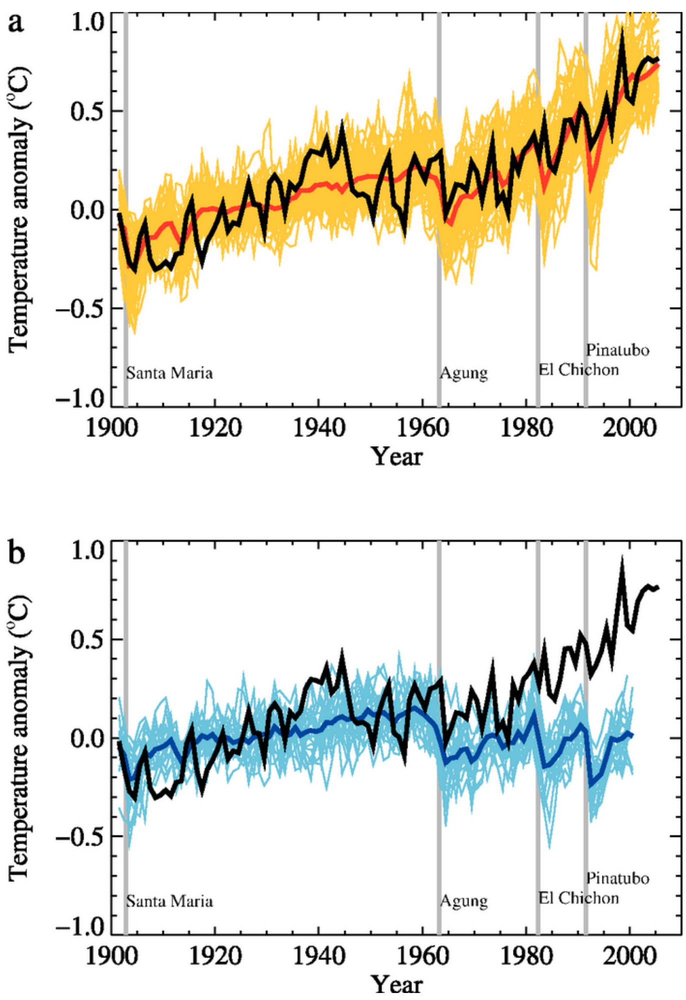


Figure 4.3 (a) Global mean surface temperature anomalies relative to the period 1901 to 1950, as observed (black line) and as obtained from simulations with both anthropogenic and natural forcings. The thick red curve shows the multi-model ensemble mean and the thin yellow curves show the individual simulations. Vertical grey lines indicate the timing of major volcanic events. (b) As in (a), except that the simulated global mean temperature anomalies are for natural forcings only. The thick blue curve shows the multi model ensemble mean and the thin lighter blue curves show individual simulations. Each simulation was sampled so that coverage corresponds to that of the observations. *Source*: Hegerl *et al*. (2007).

4.4.5 Generating synthetic climate data

While it may be possible to use climate model outputs to investigate how a given system may change in the future, this can require a lot of expertise and may also be very resource intensive. Another way in which future climate data may be obtained is to generate synthetic data. This means, thinking up some plausible ranges for changes in climate variables of interest, and then sampling from those ranges to generate some future climates. The task is simply to consider what is or may be plausible. These ranges could be based on, or guided by the ranges suggested by climate models, which may be available in published reports, for example the IPCC AR4 (e.g. Lempert & Groves 2010), or could explicitly seek to explore a larger range of variation than suggested by the climate models (e.g. Prudhomme *et al*. 2010). For example, one may want to consider how a system would function under a range of temperature increases from say 1 to 6 degrees Celsius, at half a degree intervals, in which case one could simply explore changes under 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, and 6 degrees C. This may be combined with increases or decreases in precipitation of say 10%, 20% and 30%. Alternatively, if for example a water company wanted to explore the effects of drought on the provision of potable water, then they could perhaps generate synthetic data which would represent the conditions under which drought arises, e.g. a series of drier than average winters and drier than average summers.

These synthetic data could be generated very simply in a spreadsheet package, or it may be possible as part of an environmental model. The use of synthetic data is often associated with a model sensitivity analysis (described in section 4.5.2), and may be best suited to exploring adaptation problems in which only a small number of climate variables are of interest, or as part of an initial risk screening approach, or preliminary analysis, as it is less resource intensive than using climate data. If synthetic data are used in an analysis, then the issue of whether or not physically plausible combinations of parameters have been generated is something that would need to be considered. If a detailed analysis is required it may therefore be advisable to use climate model outputs.

4.4.6 Climate analogues

Climate analogues provide a means with which we may be able to learn about the future climate that may be experienced in a given region, based on past and present weather and climate conditions that have been or currently are in existence.

4.4.6.1 Temporal analogues

Essentially, for the purpose of informing or assisting with adaptation planning, temporal analogues involve obtaining evidence from the observational record, where a given weather event resulted in some change in a given system function, and any response strategies that were adopted to cope under these conditions. An example might be the effect of a particularly hot summer e.g. 2003, on the provision of care for the elderly in a given city. What were the strategies that were implemented in order to adapt to such events? Could any lessons be learnt from these experiences and written up into a new or modified management strategy for dealing with such cases? For example, developing or updating an existing heatwave management plan.

This approach is conceptually similar to the use of critical thresholds, where the aim is to try and understand the way in which systems have been affected by past climate events, and possibly any adaptation mechanisms that proved effective, from which you can learn, thus helping to inform planning. If such thresholds, or analogues, can be identified, it would also be possible to ask the question how might the occurrence and intensity of such events change in the future. This could then provide greater clarity on the need for action, and what kind of action. While it may be possible to identify analogues, it will clearly be necessary to consider whether adaptation mechanisms implemented in the past are still applicable today, as there may have been considerable changes in the available technologies and other issues, since a given analogue was experienced. Nevertheless, the use of temporal analogues can provide a useful and informative means of framing the issues and thinking about adaptation, and could be used as a relatively low resource intensive approach, perhaps as part of an initial risk screening.

4.4.6.2 Spatial analogues

Essentially, spatial analogues involve learning from other areas of the world that already experience a climate, which within some period of time, may be the kind of climate that is expected to be heading your way, as a result of climate change. As such, it may be informative to investigate what kind of management strategies or technologies or techniques are used to deal with climate in these areas. There may be some value in this approach, but it is very important to be informed of the limitations of this approach, because while there may be similarity in expected temperatures, or precipitation, there are a number of additional factors which will likely be important to the functioning of a given system, which are site specific, and which will not change under climate change. For example, when considering possible changes in crop varieties that may be grown, latitudinal variations in light conditions and day length, along with soil conditions, will be equally important as temperature and precipitation, to the success of a given crop type (Carter *et al*. 2007). If a spatial analogues approach is adopted it is important that the implications of the limitations of a given analysis are understood and reported.

One example of an analogues approach to informing climate adaptation is the Climate Analogues tool from the Consultative Group on International Agricultural Research (CGIAR), which attempts to provide temporal and spatial analogues for the discovery of potentially viable crops to grow in different parts of the world, under future climate conditions. A link to this tool is provided in chapter 6.

4.4.7 Climate indices and extremes

Both observed and modelled data can be used to obtain information on changes in climate indices and extremes (defined as any change above or below a commonly accepted statistical measure of rarity e.g. 95th or 5th percentile).

Climate indices report information relating to changes in climate variables, which may be of relevance to different economic sectors, for example in the energy sector, the number of cooling degree days, and heating degree days are used to help plan and manage energy demand. Indices may be derived or calculated directly from climate observations, or modelled data.

In terms of adaptation planning, it is the case that direct experience of, or information related to extremes can often provide the stimulus for action, in that the direct experience of a climate-related event heightens awareness of the risks, and may create the political commitment and space for taking action, this is referred to as the 'policy windows hypothesis' (Adger *et al*. 2007). Often, information relating to extremes is presented in the form of indices, for example, the number of summer days with maximum daily temperature above 30 degrees C. Information on climate indices and extremes can be used to form either a quantitative or qualitative assessment of what the changes may mean or indicate for being able to meet business objectives, e.g. there may be n days more of event y; there may be an increase/decrease in the number of events of y. It is also worth stating that the use of observed changes in indices and extremes, and any trends in these, can be very powerful in raising awareness of climate change, establishing an evidence base, and helping build a case for the need for adaptation. If the observational data sets can show a clear trend of change then this can often be sufficient evidence to stimulate action.

Figure 4.4 provides examples of ways in which climate extremes may change under a changing climate. Possible changes in the mean, variability and shape of climate statistics will lead to different possible changes in extremes. It should be clear from figure 4.4, that even relatively small changes in the climatology of a given climate variable, could have significant implications for the frequency and magnitude of extreme events (Coumou & Rahmstorf 2010).

4.5 Simulating the impacts of climate change

While the use of climate data may be of use to develop a broad understanding of possible ways in which a system may be affected under a changing climate, the question that really needs to be answered is: how will my system be affected by these changes in climate, and thus the ability to meet business objectives? In other words, we need to understand our system sensitivity to changes in the key driving variables, both climate and non-climate. If we have an accurate understanding of our system sensitivity then this provides powerful information which we can use to inform the development of adaptation strategies and actions.

As described in chapter 3, to obtain this system understanding we need a causal model, which describes either quantitatively, or qualitatively, the relationships and inter-relationships between the driving variables that are relevant to the functioning of a given system. This section provides a discussion of some of the main methods and tools that can be used to develop an understanding of how a given system functions.

4.5.1 Impact models

A powerful way of obtaining more detailed information on the way in which a given climate sensitive system may respond to changes in climate is through the use of environmental modelling tools, which are sometimes also referred to as climate impact models (Challinor *et al*. 2009). These models may be developed on the basis of empirical relationships (statistical models), or an understanding of fundamental physical processes (process models), and are used to model various environmental systems and economic sectors, e.g. water, agriculture, forestry, coastal systems, energy, food. Impact models will typically be driven by climate variables, and other system relevant variables, and may offer some scope for the inclusion of socio-economic variables. These models may be used to perform sensitivity analyses to try and understand better the way in which a given system responds to climate, and should ideally be able to simulate or integrate the action of adaptation actions or strategies on the system function (Lempert & Groves 2010). These kinds of models may already be used operationally in the water and energy sectors, for example.

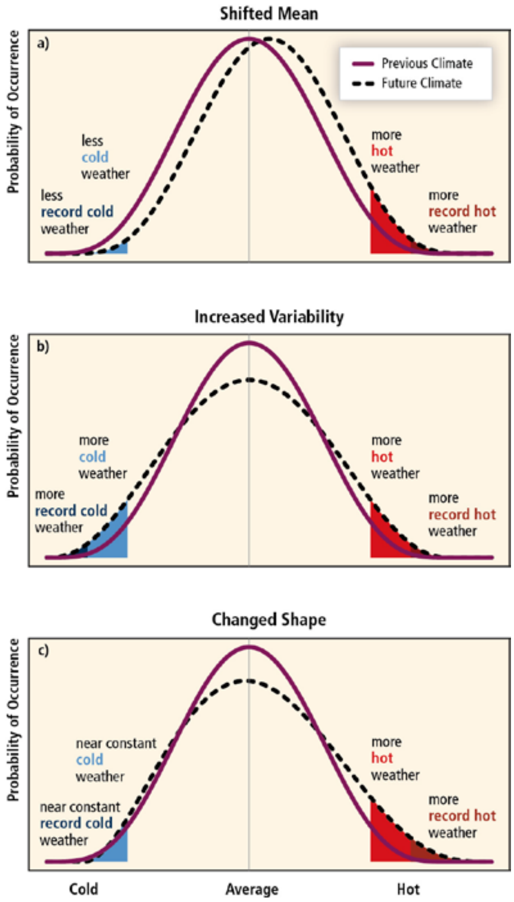


Figure 4.4 The effect of changes in temperature distribution on extremes. Different changes in temperature distributions between present and future climate and their effects on extreme values of the distributions: a) effects of a simple shift of the entire distribution toward a warmer climate; b) effects of an increased temperature variability with no shift of the mean; and c) effects of an altered shape of the distribution, in this example an increased asymmetry toward the hotter part of the distribution. *Source*: Lavell *et al*. (2012).

4.5.2 Model sensitivity analysis

A model sensitivity analysis investigates the way in which the model output responds to variation in the model inputs, and can be used to determine the relative importance of the model parameters in driving variation in the model output (Saltelli *et al*. 2005). For example, a crop growth model could be used to investigate the effect of temperature on crop yields.

If we have a model of a system, it will be possible to conduct sensitivity experiments, where we explore a wide range of variation in the climate and non-climate parameters, and analyse how the system (model) responds. This could be done with modelled climate data, or a less resource intensive approach would be to generate synthetic climate data.

Sensitivity analysis can be used to help identify those factors which have most influence on the functioning of a system, and thus can be very instructive in the search for adaptation actions or strategies (Dessai & Hulme 2007). Moreover, it may be possible to explore the efficacy of potential adaptation actions across a large range of possible futures, using a sensitivity analysis. This would serve to highlight where, or under what conditions, a given adaptation strategy may be sub-optimal or less robust. This kind of information would be of great value in the process of selecting adaptation strategies.

Model sensitivity analysis provides a powerful means of learning about the functioning of a system, and is less resource intensive than generating a large climate model ensemble. The results of a model sensitivity analysis can also be used to generate what are known as impact response surfaces.

4.5.3 Impact response surfaces

Model sensitivity analyses can lead to the identification of a set of model parameters which are most influential in driving the system response. Using this approach it may be possible to generate a functional relationship between a small set of model parameters, and the system response (Fronzek *et al*. 2010). In so doing, it is possible to generate what is known as a climate impact response surface, which represents this functional relationship. This system response could be a threshold value of high relevance to a given business objective. For example, it may be necessary to have a certain water level in a river to allow transportation of manufactured goods. An impact response surface could be used to investigate how often in the future this threshold level would be met, and thus help support decisions in relation to developing adaptation measures. An example of an impact response surface is shown in figure 4.5.

This method provides a rapid and quickly updatable and reusable tool for understanding the effects of changes in climate on the system response. As new climate data sets become available they can simply be plotted over the surface (assuming no change in the functional relationship) and analyse if anything has changed. This attractive feature of reusability, and being easily updatable as new climate information becomes available or as business objectives change, means that this approach may represent a good return on any investment made to develop such tools, and is easily incorporated and used as part of an iterative review process of climate risk management.

These response surfaces serve to highlight visually when business objectives may be vulnerable, or alternatively where a particular opportunity may become worth exploiting. Challenges arise when this response surface cannot be defined with less than four parameters, because one of the major attractions of response surfaces is the rapid assessment that visualisation provides. With more than three parameters visualisation becomes difficult.

As such, this approach is most suitable for systems whose response is driven very strongly by a few climate variables (Prudhomme *et al*. 2010). Also, the accuracy of these surfaces compared to a full modelling approach should be assessed and reported. Also consideration of the uncertainty in the modelled response itself needs to be considered in the sense that a different impact model may give a different surface.

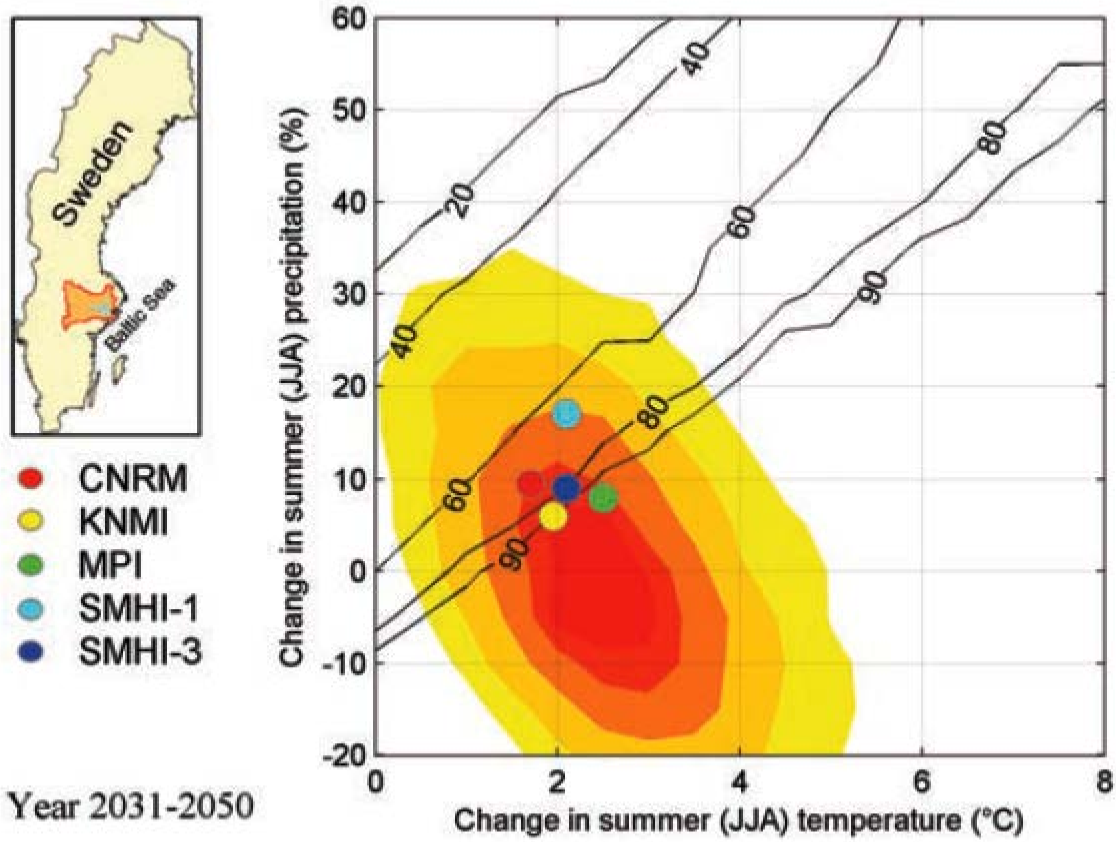


Figure 4.5 An example impact response surface for Lake Mälaren in Sweden. Diagonal black lines are the likelihood in percent of summer water level being below the target operating threshold for a consecutive period of 50 days for the change in summer temperature and precipitation. Climate projections for the time period 2031-2050 are shown as probability density plots in the coloured area, which encloses approximately 90% of all projected outcomes. The coloured dots are projections from regional climate models. Clearly in this example there is a high likelihood, based on the approach taken, that this threshold will be under threat, and they would need to find ways to adapt. *Source*: van der Linden & Mitchell (2009).

4.6 Actionable and usable data: get involved

Given the fact that adaptation is an action and solution oriented real-world problem, there is an increasing awareness of the need for two-way dialogue between the users of climate information and the scientists who generate it, in order to help tackle the problem more effectively (Lemos *et al*. 2012). To provide decision relevant information, it is imperative that a sustained two-way dialogue is established between providers and users, to help ensure the generation of actionable and usable climate data and information.

There has been research to suggest that there are three essential elements to ensuring “actionable” climate knowledge (Cash *et al*. 2003, Meinke *et al*. 2006). These essential elements are: *saliency* (the perceived relevance of the information), *credibility* (the perceived technical quality of the information), and *legitimacy* (the perceived objectivity of the process by which the information has been produced). To ensure salient climate information is developed demands that the climate related problems faced by different economic sectors are well known and explained before product development is embarked upon. This requires the gathering of key stakeholders and decision-makers from different economic sectors, together with scientists and other experts, to engage in a discussion, and to learn about their adaptation challenges. This engagement requires a proper discussion of the issues and possibilities for development of climate products, where the needs and requirements of users can be reconciled with what the science is currently able to deliver. Credibility in the development of climate information and products, demands that efforts are made to report and inform on the reliability of different products, both in relation to the methodological approach, and the subsequent model results. The legitimacy of the process by which climate information and products are developed is related to the way in which the needs of different users have been considered and realised in the final product. This involves having a sustained, mature, constructive, two-way dialogue between users and providers, where users can make their needs clear, and providers can explain the status of the science to meet these needs, and the implications for possible product development. A related issue that needs to be considered in any dialogue process is that any climate products need to be usable (Lemos *et al*. 2012). This means that they should integrate well with existing business practices, and expertise, if the products are to be used. This is another part of the dialogue process that needs to come from users.

Ensuring actionable and usable products are delivered will thus demand a large investment of time and effort on the part of both adaptation practitioners and scientists providing the climate information, and developing good communication networks is a major requirement for supporting the adaptation process.

4.7 Chapter summary

This chapter has shown that:

- There are a range of different methods and tools available that may be used to assist with assessing climate risks.
- Careful consideration is needed to understand what the limitations and drawbacks of given methods and tools are, and also the critical importance of understanding the various sources of uncertainty in any modelling or observational data that are used.
- Methods and tools should be used that contain the appropriate level of detail that is accurate enough to answer the question that is being asked, don’t overcomplicate.
- The meaning of and implications that derive from modelling studies or outputs should be considered carefully, and should not be interpreted as covering all possible or plausible futures. Sensitivity studies are not predictions. The most important aspect of any modelling exercise, is the way in which the implications are understood, and what these may mean for informing the adaptation decision making process.

5 Developing an Adaptation Strategy

Chapter Highlights

- Provides a discussion of the implications of uncertainty for developing adaptation strategies and actions.
- Reviews some of the most commonly applied tools for appraising adaptation strategies and actions.
- Provides a detailed discussion of the robust decision making framework.

5.1 Introduction

Having carried out a risk assessment, the next stage of the risk management framework is to identify and assess adaptation strategies that may treat these risks. Developing an adaptation strategy is about forward planning to deal with future climate risks, and will take place under conditions of deep uncertainty. What kind of approach would you take in dealing with this uncertainty? Would you seek to predict the most likely future outcome and plan accordingly? Or, would you instead acknowledge that uncertainty exists, that you will never have 100% certainty, and that you may not be able to say what the most likely outcome will be, and thus plan accordingly? In other words, would you seek to find an optimal strategy, or one that were more robust to uncertainty in how the future may turn out (Rosenhead *et al*. 1972). The answer to this question will depend on the nature of the uncertainty associated with a given adaptation strategy, and the various sources from which this uncertainty derives.

An additional factor that might need to be considered in answering this question however, is the recognition that decisions made in the real world, are informed by a range of different competing considerations (e.g. political, social, economic), and not simply on the basis of a piece of scientific analysis. This is particularly the case in adaptation, where a range of different stakeholders may be party to a decision, and who may have widely varying values and perspectives, which need to be accommodated in a participatory process.

This chapter considers two different decision making frameworks of how decisions can be made with regard to developing adaptation strategies. The methods and tools described in the previous chapter may be applied under both these decision making frameworks.

5.2 What are the implications of uncertainty for adaptation planning?

Because of the various sources of uncertainty in adaptation decision making, it is simply not possible to predict with certainty what the future world will be or look like. The only credible way of acknowledging and dealing with this uncertainty is to explore as wide a range of different possible futures (determined by changes in climate and non-climate factors), as possible. The task then is to endeavour to understand what this may mean for the functioning of a particular system, and the effect it may have on being able to successfully meet business objectives.

It is important to state that regardless of what kind of range of modelled uncertainty is explored in an analysis, it will only represent a sampling of the range of possible futures. Exploring model uncertainty provides value in that it allows us to conduct "what if?" scenarios, and consider how we might respond, either to reduce our threats or seize opportunities. It does not however, mean that we have covered all possible future worlds or climates. It is always possible that because of our lack of complete knowledge as to what may happen in the future, that we may experience conditions that we had not planned for, i.e. surprise events. If we fail to act in recognition of this fact then any plans that we make will be more vulnerable to such events. This can lead to overconfidence in an analysis performed on a range of uncertainty generated solely from the models, without adequate acknowledgement of the limitations of the models, and the other sources of system uncertainty that can weaken strategies developed along these lines. Models are to be used to generate insight which may inform the decision making process. We should not fool ourselves into thinking that because we have explored a wide range of model uncertainty, that we are well prepared, and it will be sensible to consider the potential for surprises, and so-called low probability high impact events (Stainforth *et al*. 2007).

5.3 To hedge, or not to hedge, that is the question

In the context of using climate and non-climate information to support adaptation planning and decision making, there are two alternative decision frameworks that are applied, a predict-then-act framework, and a robust decision making (RDM) framework (Weaver *et al*. 2012).

1. **Predict-then-act**: this has been the most commonly adopted framework, under which optimal strategies are sought which seek to maximise the expected utility of a given adaptation strategy. This framework relies on the ability of models to predict the 'most likely' future (Lempert *et al*. 2004). To determine the 'most likely' future, means that we need to be able to assign probabilities to our predictions. Optimising approaches place a great emphasis on the ability of the science to predict the future, which as we have seen in chapters 3 and 4, for good reasons, has a lot of uncertainty.
2. **Robust decision making**: this framework has more recently gained traction in the adaptation arena (Lempert & Schlesinger 2000, Lempert *et al*. 2006, Lempert & Collins 2007, Lempert & Groves 2010, Kunreuther *et al*. 2013). This framework seeks to minimise the regret associated with a given adaptation strategy, by evaluating a number of different strategies and selecting that strategy which performs relatively well compared to the alternatives, across a large range of future scenarios. This relative performance measure is the robustness criterion, and because it doesn't seek to provide an optimal outcome under one 'most likely' future, provides a hedge against uncertain futures. The performance criterion is the level of robustness offered

by a given strategy, in the sense that it fails to meet its objectives on fewer occasions, or is less sensitive to uncertainties, than the alternative strategies.

Deciding which of these two frameworks is most suitable for application, essentially comes down to how seriously a given adaptation strategy is, or may be afflicted by, the issue of deep uncertainty. Lempert *et al*. (2004), characterise deep uncertainty as being the situation where "*decision makers do not know or cannot agree on: 1) the system models, 2) the prior probability distributions for inputs to the system model(s), and their interdependencies, and/or 3) the value systems used to rank alternatives*".

This issue of deep uncertainty in adaptation decision making thus begs two questions: 1) how much confidence do we have in our models to be able to predict the future, and assign probabilities? and, 2) how may we provide some room for accommodating competing value systems of what an acceptable adaptation strategy may be?

In answer to the first question, as we have seen in previous chapters, there will always be uncertainty associated with any model predictions, be they climate models, impact models, or conceptual models. Further, it is worth considering that adaptation decision making is not simply informed by climate information, but also a range of non-climate, socio-economic and socio-political factors. Can we credibly assign probabilities to these factors? Is the uncertainty associated with these factors likely to be greater than that associated with changes in climate? In other words, when considering which decision making framework to adopt, it is worth asking whether using probabilistic model data is well suited or matched to the nature of the real world adaptation decision making process.

In answer to the second question, even if we were able to assign probabilities, and thus determine an optimal adaptation strategy, for whom exactly would this strategy be optimal? In the real world, where there may be various stakeholders involved in approving adaptation decisions, it is not unlikely that there will be numerous competing views as to what the optimal strategy might or should be. The predict-then-act framework offers less scope for deliberation about alternative strategies and social learning, than the RDM framework, and this may have a range of implications for the possible implementation of a given adaptation strategy.

Clearly, these issues will be more or less important depending on the context and nature of a given adaptation problem, and the uncertainty associated with a given strategy. If the strategy does not affect external stakeholders, has a short decision lifetime, has flexibility, and/or is a no, or low regret option, then the predict-then-act framework may be suitably applied. If however, the strategy has a long decision lifetime (and is thus more vulnerable to broken assumptions in the modelling), limited flexibility, and/or involves external stakeholders, then an optimal strategy designed under the predict-then-act framework, may be too vulnerable or risky in the face of futures different from what was considered most likely when the decision was made. In these cases, a robust decision making framework is likely to be more suitable. In practice, there may also be pragmatic reasons for adopting one or the other decision framework.

Irrespective of which decision making framework is adopted, there are a range of different methods available to support this stage of the decision making process, and we review some of the main methods here. The decision context is key to the application of a given method, and the limitations of the method for addressing a given adaptation problem should be considered and the implications for decision making understood, reported and documented. The following sections now discuss the two decision frameworks and tools that may be applied in each in more detail.

5.4 Optimising strategies

We review here some of the main methods that are typically associated with the development of an optimising adaptation strategy (Ahmad *et al*. 2001). It is important to state however, that the methods described in this section, may also be applied under the robust decision making framework (Lempert *et al.* 2012).

5.4.1 Cost-benefit analysis

Cost-benefit analysis is a commonly applied tool in business and economic decisions and is not described in detail here. We focus instead on the suitability of its application for supporting adaptation decision making, given the nature of uncertainty in adaptation planning.

Cost-benefit analysis (CBA), is a method which seeks to provide the greatest return or utility (benefit) of outcome, in relation to the associated costs of a particular adaptation option. This net benefit (e.g. reduced damage costs from climate impacts) is assessed based on one criterion – monetary cost, no other decision criteria are considered. CBA duly seeks to identify the best or optimal option, based on this criterion. CBA relies on knowing exactly what the most likely future may be in order that all possible costs and benefits may be valued, and an optimal solution found. With uncertainty in climate this is simply not possible, and thus it is not possible to arrive at a stable estimation of any net benefit (Kunreuther *et al*. 2013). In other words, if we don't know the probabilities of future climates (and/or the probabilities are ambiguous), and the associated costs and benefits, how can we decide with certainty what the best option is?

Nevertheless, there may be situations where CBA can be applied with value in adaptation decisions. For example, where the adaptation actions can be characterised as no regret (such that it doesn't matter what the climate does), or where the actions available offer flexibility (such that the failure of any optimised action can be undone relatively easily), or the feasible actions are limited. In such cases, CBA may be used, but a sensitivity analysis (SA) should be performed over a range of possible futures, to investigate how vulnerable or sub-optimal the strategy may be. It may well be that one adaptation action is optimal across a wide range of futures, and this would provide a rational basis on which to select the particular option, while at the same time, the SA would shed light on the effect of an uncertain future on system performance, such that any residual uncertainties under given scenarios may be known, and alternative measures or contingencies for dealing with these 'residual' risks may be considered. This can be thought of as a hybrid approach to adaptation, where we seek to optimise under certain situations, but recognise the uncertainty by planning ways of coping or adapting to other possibilities, rather than pretending the uncertainty doesn't exist. In addition, the decision can be reviewed at a later stage as part of a periodic review, or as new information becomes available (e.g. improved system understanding, climate data).

Also, it is very difficult to assess the costs and benefits of future impacts in a number of adaptation problems, and so there is deep uncertainty, which doesn't accord with the philosophy of CBA. Moreover, given the nature of adaptation decisions and that they may affect and involve a large range of issues and stakeholders, it may not be realistic or practical to base selection of an adaptation strategy purely on monetary terms, and additional factors may need to be considered.

5.4.2 Multi-criteria analysis

Clearly, in making adaptation decisions, there may be other considerations in addition to monetary cost. Multi-criteria analysis (MCA), provides a framework under which criteria measured in non-monetary and monetary units can be considered e.g. efficacy, stakeholder acceptance, ethics, social, and environmental impacts, among others. The goal of MCA is to determine the best or optimal adaptation option, based on an aggregate performance score. The MCA process can be broken down into the following steps:

1. Develop a set of adaptation actions to assess.
2. Establish a range of criteria against which the adaptation actions will be assessed.
3. Score the relative performance of the actions against the selected performance criteria.
4. Assign a weight to each criterion to indicate their relative importance.
5. Aggregate the scores to provide an overall performance score for each action.

One issue thus associated with a MCA is the assignment of weights and scores to the different criteria (which depending on the nature of the adaptation problem may involve many stakeholders all of whom may assign different weights and scores). Nevertheless, here too a sensitivity analysis (SA) could be performed in which a range of different weights are explored, whereby the effect on the aggregate score of the different adaptation strategies could be investigated. The uncertainty around a range of possible future climates could also be included in this sensitivity analysis. The task then would be to determine whether there was one adaptation strategy that proved optimal across the investigated range, or whether certain strategies performed better under given conditions. This analysis can be performed on the basis of the aggregate score, or a ranking or rating system. Table 5.1 provides a hypothetical example of a MCA.

This issue of being able to assign weights and scores to a number of different criteria, and explore the importance of the various criteria over a range of different futures or scenarios, in a sensitivity analysis, implies a potentially large resource requirement for pursuing a MCA. While there are some software tools available for dealing with this, the arrival at a final decision may prove problematic if there are too many possibilities, and no clear adaptation option 'winner' emerges across all scenarios. Careful analysis of the adaptation problem context and key factors in determining the feasibility of adaptation actions, is therefore required to keep the dimensionality of the problem to a manageable level. As a result, some small number of scenarios may be investigated, which perhaps span an expected range of possibilities.

MCA still suffers from the same weakness as CBA in that it still tends towards optimising on an uncertain future even with an SA, although the consideration of a number of factors, and stakeholder consultation, may serve to help move away from one ideal 'optimal' solution.

5.4.3 Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) is a method which may be used to select between different adaptation strategies or actions based on the relation between costs and benefits, when the benefits are not measured in monetary terms, but rather the adherence or compliance with a given company objective or environmental regulation. This could, for example, be the delivery of a certain volume of potable water for public consumption, or acceptable levels of industrial pollutants, which, changes in climate may make more difficult to meet, and thus necessitate adaptation. The benefit would be compliance with a given target, and the costs would be the cost of implementing the adaptation option which would ensure targets were met.

In other words, cost-effectiveness is a way of selecting the least expensive action to meet a given target. It is important to state however, that this least expensive action is only in relation to the competing actions. The question of whether the least expensive option is economical to a business in absolute terms is a different question, in which case other options would need to be explored. In other cases, if an organisation has a fixed budget, CEA can also be used to determine which of a range of different actions would provide the greatest effectiveness in reducing risk to a given climate impact, for the financial cost.

Again, uncertainty needs to be dealt with in CEA, and this would again entail running sensitivity analyses over a range of different futures to understand where or under what conditions, a given adaptation action fails to meet the business objective or target.

Table 5.1 Hypothetical example of a decision matrix for multi-criteria decision analysis. Each of these criteria would have a different weighting or influence in the calculation of a score or ranking. Apart from the cost estimates, all other criteria have been assigned an ordinal value from 1-5, where 1 is low and 5 is high. The values assigned are absolute values based on consideration of each strategy on its own merits, not in terms of relative performance compared to the other strategies.

	Criteria						
Adaptation action	Cost (€)	Stakeholder acceptance	Ecological impacts	Health and safety impacts	Mitigation co-benefits	Effectiveness	Potential for maladaptation
Action 1	200-400	3	1	1	1	3	2
Action 2	60-120	5	3	2	1	2	2
Action 3	300-700	1	2	3	4	4	1
Action 4	200-300	2	1	3	3	3	3

5.5 Robust strategies

This section describes the robust decision making framework.

5.5.1 Robust decision making

Under the robust decision making framework, one accepts that there are multiple plausible futures, and seeks to explore how a given business objective may fare under a range of different futures, rather than seeking the most likely outcome (Weaver *et al*. 2012). The approach starts first with the candidate adaptation strategies, and then uses a modelling framework which samples a range of uncertainty in the main decision relevant system driving variables, to generate a large number of scenarios. The question then asked is, under what future conditions would a particular adaptation strategy fail to meet its business objectives, as represented by some performance criterion e.g. a power station operating at 90% capacity throughout the year.

The RDM approach is an iterative method which tests out different candidate strategies, seeking to characterise the vulnerabilities associated with each, and uses this information to inform and identify alternative strategies that may be more robust. The robustness criterion represents some level of satisficing, in the sense that a strategy performs relatively well compared to the alternatives, across a wide range of scenarios. The power of the RDM approach is that it is less vulnerable to broken assumptions about the future i.e. what the climate impacts might be. The RDM approach is summarised schematically in figure 5.1, and section 5.6.3 provides a detailed step by step guide of how the RDM process is carried out in practice. Appendix 2 provides two case studies of the use of RDM in practice. It is worth stating that the RDM approach is entirely consistent with the risk management process, in the sense that the problem is first structured effectively, and then the approach combines the risk assessment stage and adaptation strategy appraisal stage of the risk management framework in one step.

As originally conceived, RDM was a quantitative computational model approach (Lempert *et al*. 2000), however, the principles involved in the approach can equally well be applied to qualitative conceptual models of how a given system functions, as recently demonstrated by McDaniels *et al*. (2012), and this is summarised as a case study in Appendix 2. It should also be apparent that robust decision making is very similar conceptually to conventional scenario planning, in that it asks “what if” questions, and explores how the system would function, and thus how adaptation strategies may perform, under a wide range of future scenarios. There are however some key advantages of RDM over conventional scenario planning, these are (based on Weaver *et al*. 2012):

1. **Greater decision relevance**: when thinking through conventional scenario planning the scenarios are typically qualitative, and may be highly speculative, thus offering less focus or direct application to the real world context. RDM on the other hand, because it uses system models specific to a given decision context to generate scenarios, provides more focus or greater structure to the problem domain, and thus are of more direct relevance to informing the adaptation decision making process.
2. **Guides the process of developing alternative strategies**: because RDM is based on the analysis of a large number of scenarios, seeking to reveal the conditions under which strategies fail to meet their objectives, this process illuminates which factors or combinations of factors, lead to strategy failure. With this knowledge or system learning, alternative strategies can be developed which can seek to directly act on these factors, and reduce their importance. In other words, RDM can focus attention on the main sources of uncertainty in causing strategies to fail. Moreover, because RDM generates a large number of scenarios, it may illuminate surprise combinations of factors that lead to vulnerabilities, which may never have been possible using a conventional approach to scenario planning. This system learning may also have other implications which can support successful adaptation, such as guiding where we need to learn more, which may lead to a more detailed modelling analysis being carried out, or informing where new research could have a major impact on helping address real world adaptation problems.

5.5.2 The RDM Process

The various steps involved in performing a RDM analysis are schematically illustrated in figure 5.1, highlighting the iterative nature of the process. Following this process involves a number of key tasks and these are broken down, and described in detail below.

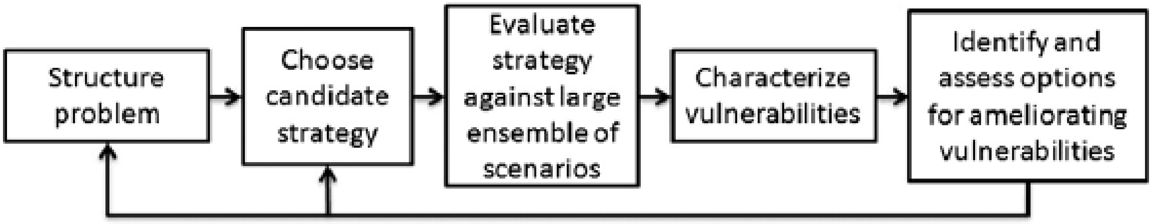


Figure 5.1 Steps involved in a robust decision making analysis. In operation, the RDM method combines steps 3 and 5 of the risk management process (risk analysis and adaptation strategy appraisal), as shown in figure 3.1. *Source*: Lempert & Groves (2010).

5.5.3 Methodological Steps in RDM

1. A model (quantitative or qualitative) is needed that describes the system response to changes in the model driving variables both climate and non-climate. It should also be possible to manipulate certain of these variables or model processes, or external conditions, such as to simulate the action of adaptation actions or strategies, and thus obtain an idea of their efficacy.
2. A range of different adaptation strategies need to be devised, which can be tested across a large range of different futures or scenarios. This process can and in most cases probably should include stakeholder participation.
3. A performance metric against which the robustness of various adaptation strategies can be evaluated is needed. This performance metric can be a relative or absolute measure – depending on the nature of the problem, e.g. the costs of operation.
4. The approach then is to identify the main drivers of change in the system response, this may be based on existing understanding from observations, experience, physical reasoning, and or in discussion with a range of different stakeholders. This discussion with stakeholders is also important to be able to define mutually agreeable plausible ranges of variation in the driving variables.
5. Having identified the main drivers of change, and established plausible ranges of variation, the task then is to generate a database containing a large number of scenarios, which are obtained by running the model using many different combinations of values of the driving variables.
6. With this scenario database generated, the next step is to assess the performance of a given adaptation strategy – and a good starting point would be to evaluate the performance of an existing strategy, to see how it would perform under changed future conditions. This evaluation of a given strategy or action, is done with reference to the performance metric, and typically involves determining whether this strategy is able to meet the business objectives. At this stage this is akin to having performed a risk analysis, and having evaluated the results, it will be possible to determine whether a given organisation considers itself to be vulnerable to climate and other changes which impact on their business objectives. They can then answer the

question: do I need to adapt my current strategy to make it more robust in the face of future changes in climate?

7. Next, having identified the performance of a chosen strategy, the task is to try and learn about the conditions under which the strategy fails. If we can do this, then we can use this information to inform the identification of adaptation alternatives which may act to address these vulnerabilities. When using a quantitative approach, this is achieved by running statistical search algorithms across the database, to identify those cases where a given policy failed, and extracting the values of the driving variables with which this failure is associated. Statistical clustering techniques may then be applied to try and identify patterns in the drivers of failure, which may then be conveniently summarised. In doing this, one is obtaining a lot of information about the system function.
8. With the information and learning obtained from steps 4-7 it is then possible to use this information to identify and develop alternative adaptation strategies, which may be expected to perform better than the existing strategy. The process is then repeated for this new strategy, and its robustness is then evaluated. This process continues until a range of adaptation options have been evaluated.
9. The task then is to be able to choose between them, as they may all offer different levels of robustness, and the final decision of what to do will then come down to the level of effort involved in implementing different strategies, and also the level of risk that a given organisation is prepared to accept – which will be determined by their risk attitude, and the level of stakeholder acceptance for different strategies. This is where the barriers to adaptation really come into play, and the need for social and organisational learning is paramount, as the adaptation decision making process or risk management process then moves on to the issue of implementing adaptation strategies.

It is also important to point out that a robust strategy may still have residual risks, for which contingency planning would be needed.

5.5.4 Benefits of the RDM Approach

Benefits associated with using RDM, other than having decisions being more robust to uncertainties, are:

1. **Facilitates a more action oriented deliberation process**: lack of certainty, or conversely too much uncertainty in climate information is often used as an explanation for not engaging with adaptation problems, in what has been referred to as the “uncertainty fallacy” (Lemos & Rood 2011). This fallacy arises on the basis or expectation, that one day we will have highly certain predictions about the future, and when we have them, then we will take action. In reality, however, this search for greater certainty is unlikely to be realised in any decision relevant timeframe, and places unrealistic expectations on the climate information. Moreover, the fact is that there will always be uncertainty, and we need to learn to accept and live with this uncertainty, and use appropriate methods for dealing with it. RDM provides a suitable way of dealing with this uncertainty, and shifts the emphasis of deliberations away from accurate climate predictions, to exploring plausible scenarios of the future, and what could we do to manage our climate risks under these uncertain futures, which is where the discussion should really be. In addition, almost all decisions an organisation may make will be made in

the face of uncertainty, and so in that sense, dealing with uncertainty in adaptation is nothing new.

2. **Provides scope for consensus building, and social learning**: because RDM is concerned with finding robust strategies, and explores many different scenarios, it provides ample scope for considering different values, which is particularly important when there are many different stakeholders involved in an adaptation decision, and RDM can be very easily applied in participatory processes. This process of engaging with stakeholders is often key for being able to implement adaptation strategies, and the RDM approach thus also offers the potential for engendering social and organisational learning.
3. **Provides information relevant to the process of developing alternative strategies**: as stated earlier in section 5.5.1, because RDM uses models to generate scenarios, exploring how a system functions, and seeking to illuminate the conditions or combination of factors under which strategies fail, it provides valuable information in directing the search for adaptation strategies which are less vulnerable to these factors, or which may be able to exert greatest influence or control over these factors, or conditions. In other words, the RDM approach provides a framework under which the chief sources of uncertainty in driving the vulnerability of a given strategy may be identified. Having identified these sources it is then possible to try and develop adaptation strategies which can act directly on these factors.

5.5.5 Drawbacks of the RDM Approach

1. Using computational methods, the RDM approach may be very resource intensive, although quite how intensive will depend on the system under study, the nature of the questions being asked, and the type of model that is being used. It is perfectly possible, and perhaps even desirable, to start off with a first pass assessment, using computationally cheap models, which can be used to explore the system function and ask basic fundamental questions about how a given system functions (Weaver *et al*. 2012). Moreover, where there are already modelling systems in place to manage certain business processes, then these can be readily adapted and applied.
2. Regardless of whether a quantitative or qualitative approach is pursued, and the amount of resources allocated, it does require a certain amount of expertise, to carry out such an approach, and as such it may be necessary to seek appropriate expert advice.
3. There is some evidence that stakeholders find it difficult to easily understand the approach, however, this is not an insurmountable problem (McDaniels *et al*. 2012).

5.6 Chapter summary

This chapter has shown that:

- An optimal strategy may be more vulnerable to uncertainty in the way in which the future turns out, depending on the nature of the adaptation problem, than a robust decision making framework.

- There are a range of different methods and tools available that may be used to assist with appraising adaptation strategies and actions.
- Careful consideration of the nature of uncertainty is required when choosing methods to apply, and whether it is a wise move to seek to optimise.

6 Resources and Further Information

Chapter Highlights

- Provides an annotated guide to further information and resources which will supplement the information contained in this guidebook.
- Hyperlinks are provided for all sources, and are broken down on a chapter by chapter basis. These resources will allow you to deepen your understanding, and/or provide materials and tools for supporting adaptation awareness raising and planning.

6.1 Introduction

This chapter provides a selection of resources from which more detail, context, and insight into some of the major issues introduced in the guidebook can be obtained. These resources include websites that describe more about a particular project or initiative, references to scientific articles, policy documents, and data sets.

6.2 Chapter 1 Introduction

Intergovernmental panel on climate change (IPCC)
The Intergovernmental Panel on Climate Change (IPCC) website provides a wealth of information relating to the activities of the IPCC. Various special reports, and all the IPCC assessment reports which provide periodic summaries of the scientific understanding of climate change, are available for free download.
http://www.ipcc.ch/

German Adaptation Strategy
Germany has a national Adaptation Strategy, called the Deutsche Anpassungsstrategie (DAS), which was adopted on the 17 December 2008. The DAS has 13 action fields or sectors of investigation and support and two cross sectional fields, and serves as a framework for adapting to the impacts of climate change at the national level.
Homepage: http://www.bmub.bund.de/en/topics/climate-energy/climate/adaptation-to-climate-change/

Report available here:
http://www.bmub.bund.de/en/service/publications/downloads/details/artikel/deutsche-anpassungsstrategie-an-den-klimawandel/?tx_ttnews%255bbackPid%255d=216

European Union Adaptation Strategy
The European Union (EU) now has an adaptation strategy that will help support adaptation activities in the member states. For more information and background documents, see:
http://ec.europa.eu/clima/policies/adaptation/what/index_en.htm
http://ec.europa.eu/clima/policies/adaptation/what/documentation_en.htm

NASA Climate Change Indicators
This website provides a wide range of graphics, maps, and data on various indicators or metrics of climate change, which might be useful for helping raise awareness of the issue within an organisation.
http://climate.nasa.gov/key_indicators

ICLEI Resilient Cities Initiative:
This website provides background information on various adaptation activities that are happening within local government and at the city level.
http://resilient-cities.iclei.org/

European Union Mitigation Activities
This website provides good background information on the activities of the European Union in relation to climate mitigation.
http://ec.europa.eu/clima/policies/eccp/index_en.htm

Carbon Disclosure Project (CDP)
The Carbon Disclosure Project provides a range of reports and papers relating to climate change mitigation activities in the private sector, and the impacts of climate on supply chains as well as other information.
Homepage: https://www.cdp.net/en-US/Pages/HomePage.aspx
All climate change reports: https://www.cdp.net/en-US/Results/Pages/reports.aspx

Nationales Komittee für Global Change Research (NKGCF)
This website provides a range of information on major research projects in Germany, within the context of global change. Reports and other documents are available for download, which might provide useful material for awareness raising activities.
http://www.nkgcf.org/index.php

Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU)
This website provides a range of information, from fact sheets, policy documents, and major detailed studies on various topics in relation to global environmental change, which might provide useful material for raising awareness and/or deepening understanding of particular issues.
www.wbgu.de

BAMS State of the Climate Report
Published annually, this report provides the most definitive summary of current observations of climate around the world, for different components of the Earth system
http://www.ncdc.noaa.gov/bams-state-of-the-climate/

6.3 Chapter 2 Adaptation to climate change: 20 questions

CIRCLE-2 EU Project
Provides a climate adaptation information portal, where searches in relation to adaptation activities within a given country or type of climate impacts are possible. This tool provides a wealth of information on a range of different adaptation activities for most countries in the EU.
http://infobase.circle-era.eu/

weADAPT
This website provides a wealth of information in relation to adaptation from across the world, including guidance, tools, case studies, details of research projects, and much more.
http://weadapt.org/

Adger et al. (2007)
This paper provides a summary of adaptation research from the IPCC Fourth Assessment Report (AR4), and serves as a useful introduction to the adaptation research arena.
http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch17.html

6.4 Chapter 3 Adaptation as climate risk management

ISO 31000:2009 Principles and Guidelines
This is a document which describes the ISO 31000:2009 risk management principles and guidelines, and would serve as useful background information or for exploring more about the risk management process in general.
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=43170

WBGU Managing Global Environmental Risks
This is an excellent and in-depth investigation of global environmental risks, which contains much very useful technical background on risk as a concept. Free download of full report and executive summaries available in German and English.
http://www.wbgu.de/en/flagship-reports/fr-1998-global-risks/

van der Sluijs et al. (2008)
This paper provides a succinct and engaging discussion of the way in which the quality of evidence established from a risk assessment can be assessed. An important part of a risk

assessment is carrying out a certainty assessment (or reporting the level of confidence that can be had in the evidence), and the assessment framework that van der Sluijs *et al*. (2008) present, could be adopted for this purpose.
http://iopscience.iop.org/1748-9326/3/2/024008/pdf/erl8_2_024008.pdf (open access)

6.5 Chapter 4 Methods and tools for climate risk assessment

Deutsche Wetterdienst
The national weather service providing a wide range of weather data and information, and observation of past climate in Germany.
www.dwd.de

NASA GISS: GISTEMP
Global observed surface temperature data.
http://data.giss.nasa.gov/gistemp

NOAA/NCDC Global Surface Temperature Data
Global observed surface temperature data.
http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/

IPCC Data Distribution Centre
Provides a range of climate model data, under various emissions scenarios.
http://www.ipcc-data.org

ETCDDI/CRD Climate Change Indices
Provides background material, publications, data sets and software tools for calculating climate indices.
http://etccdi.pacificclimate.org/

NKGCF Regional Climate Modelling pages
Background information and summaries of workshops and publications on regional climate modelling.
http://www.nkgcf.org/remo_start.php
http://www.nkgcf.org/files/aktuelledownloads/Regionale_Klimamodelle_low.pdf

Shell Scenarios Web Site
This website provides some excellent background on the use of scenarios as applied by Royal Dutch Shell in their forward planning. There are also a number of useful resources available for download, which will aid understanding, and could assist in developing and using your own scenarios.
http://www.shell.com/global/future-energy/scenarios.html

EUROSTAT
A wide range of different socio-economic data sets for the EU nations that might be of value in risk assessments.
http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

DESTATIS
A wide range of different socio-economic data sets of past and futures possible changes, for Germany.
https://www.destatis.de/DE/Startseite.html

World Bank World Development Indicators
A wide range of different socio-economic data sets of past and some future possible changes, at the global level.
http://data.worldbank.org/data-catalog/world-development-indicators

CGIAR Temporal and Spatial Analogues Tool
A web based tool for investigating where future suitable climate conditions for different crop types may be found.
http://gismap.ciat.cgiar.org/analogues/

European Commission Joint Research Centre Sensitivity Analysis Pages
This website provides excellent background and resources on the approach and use of sensitivity analysis, including tutorials, software resources, and an FAQ.
http://ipsc.jrc.ec.europa.eu/?id=752

Shared Socio-Economic Pathways Database
This website provides access to a database of projections of a number of socio-economic variables that may be of relevance when carrying out climate risk analyses, including population by age, sex, and education, and GDP.
https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about

Euro-Cordex Regional Climate Model Data
This website describes the availability of regional climate model data from the Euro-Cordex project. These data are available for non-commercial research, and some restricted data sets are available for commercial use.
http://www.euro-cordex.net/EURO-CORDEX-Data.2613.0.html#c9791

Carter et al. (2007)
This paper provides a summary of adaptation assessment methods from the IPCC Fourth Assessment Report (AR4), some of which are covered in this chapter, and accordingly provides a suitable supplement to the information covered in chapter 4 of this guidebook.
http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch2.html

6.6 Chapter 5 Developing an adaptation strategy

PRIMATE MCA Tool
The Probabilistic Multi-Attribute Evaluation, software and guidebook freely available, from the UFZ.
https://www.ufz.de/index.php?de=14384

Shaping the Next 100 Years
Discussion around robust decision making and planning under uncertainty.
http://www.rand.org/pubs/monograph_reports/MR1626.html available as a free ebook pdf for personal use.

Weaver et al. (2012)
This paper provides an excellent discussion and examples of the use of the robust decision-making framework.
http://wires.wiley.com/WileyCDA/WiresArticle/articles.html?doi=10.1002%2Fwcc.202

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EU 2013b, EU Adaptation Strategy
http://ec.europa.eu/clima/policies/adaptation/what/documentation_en.htm
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:DKEY=725522:DE:NOT

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Appendix 1 RCPs and SRES scenarios

What are emissions scenarios, and why do we need them?

It is not possible to predict for certain what future changes in the development of the global economic system, demographics, technology, land use and land cover patterns, and energy production and intensity, may occur. These factors all determine how fossil fuel intensive future human activities will be, and thus how rapidly the emission of greenhouse gases and pollutants, may accumulate in the Earth's atmosphere. If we are interested in using climate models to try and understand how the future climate may evolve, then we need to be able to develop emissions scenarios, which provide plausible alternative trajectories of future emissions. Because we cannot predict the future development of human society, it is important that a range of different plausible emissions scenarios are developed. There are two main groups of emissions scenarios that are of relevance to developing climate scenarios, these are the IPCC Special Report on Emissions Scenarios (SRES), and the new set of emissions scenarios, the Representative Concentration Pathways (RCPs).

Using these emissions scenarios with climate models, provides a basis upon which a range of "What if?" questions can be posed, and the efficacy of various adaptation strategies and actions explored.

What are the main differences between the IPCC SRES and RCPs emission scenarios?

The chief difference between these two groups of emissions scenarios is their starting point. Whereas the IPCC SRES started with the socio-economic factors and developed emissions from this which would then lead to some change in the radiative forcing of the Earth's atmosphere, the RCPs start with a given level of radiative forcing, under which a range of different socio-economic conditions could be consistent (Moss *et al*. 2010). In other words, using the RCPs permits more flexibility in exploring scenarios of possible changes in future human society, consistent with a given level of radiative forcing, rather than just having a prescribed route. Another key difference between the SRES and RCPs scenarios, is that the RCPs contain explicit mitigation scenarios, and thus the possibility to explore policy intervention, which the SRES scenarios do not. The differences between the SRES and RCPs in terms of fossil fuel and industrial CO_2 emissions is illustrated in figure A1.1, and in terms of global mean temperature change in figure A1.2.

Why do we need the new RCPs scenarios?

Moss (2010), outlines three main motivating factors for the development and application of the new RCP scenarios, these are summarised below:

1. We have nearly a decade of additional observation and learning about the functioning of the Earth system, and socio-economics. As such, this new information should be represented in the emissions scenarios.
2. Advances in the development of climate models, and climate science in general demand that new scenarios are developed which can make use of these advances.
3. New information needs of end users. As the importance and perception of the climate challenge has grown over time, end users have become more demanding of

the climate scenarios. As such, there is increasing demand for scenarios which consideration policy intervention in the form of mitigation.

Overall, these issues mean that the scientific community is effectively responding to a requirement for the ability to explore the effect of policy on climate, and also that the new RCPs scenarios should reflect our current best understanding of the Earth system.

What are the RCPs?

There are four RCPs which span a range of plausible development pathways in regard to emissions and land use, but they should not be interpreted as spanning or representing the full range of possible future development pathways – they are, as the name suggests, representative. The RCPs obtain their names from the target level of radiative forcing (relative to pre-industrial values), in the year 2100. Each RCP describes a possible future evolution of atmospheric composition. Some key characteristics of each of the four RCPs are summarised in table A1.1 below.

Table A1.1 Summary of some key characteristics of the RCPs.

Representative Concentration Pathway	Radiative forcing and (CO_2 eq (ppm))*	Type of pathway
RCP3-PD / RCP2.6	2.6 W/m^{-2} (~490 CO_2 eq)	Peak and decline
RCP4.5	4.5 W/m^{-2} (~650 CO_2 eq)	Stabilisation without overshoot
RCP6	6 W/m^{-2} (~850 CO_2 eq)	Stabilisation without overshoot
RCP8.5	8.5 W/m^{-2} (~1370 CO_2 eq)	Rising radiative forcing

*CO_2 eq, is CO_2 equivalents, which is a way of expressing the combined radiative forcing effect of CO_2 and other greenhouse gases in units of CO_2 parts per million (ppm). It is analogous to converting the price of consumer goods in different currencies into one single unit of currency for example the Euro, or US Dollar.

RCP3-PD and **RCP2.6** are used interchangeably to refer to the same concentration pathway. This comes about due to the particular characteristic of this RCP which exhibits a clear peak and decline path, hence the PD for peak and decline. A peak radiative forcing of ~3 W/m^{-2} would be achieved by mid-century, before declining to 2.6 W/m^{-2} at the end of the century. The RCP3-PD is the most stringent mitigation scenario, with emissions of fossil fuel CO2 peaking in 2020, declining from thereon, and going negative towards the end of the century (figure A1.1).

RCP4.5 and **RCP6** are both stabilisation scenarios, meaning that the level of radiative forcing stabilises at 4.5 W/m^{-2}, and 6 W/m^{-2} respectively, shortly after 2100, and doesn't overshoot this level. For RCP4.5, while the original intention was to have stabilisation after 2100, in practice, radiative forcing stabilised around 2080, this is simply the way the modelling results turned out (A. Thomson, *personal communication*). Emissions of fossil fuel and industry CO_2 are higher in the RCP6 than RCP4.5 scenario (figure A1.1), and these two scenarios may be viewed as representing cases where there is mitigation leading to high and intermediate levels of radiative forcing, respectively.

RCP8.5 may be thought of as a "business as usual" scenario, in which there is no policy intervention, and emissions of greenhouse gases continue to increase over the course of the 21st century (figure A1.1), and radiative forcing does not stabilise shortly after 2100, but rather continues to rise.

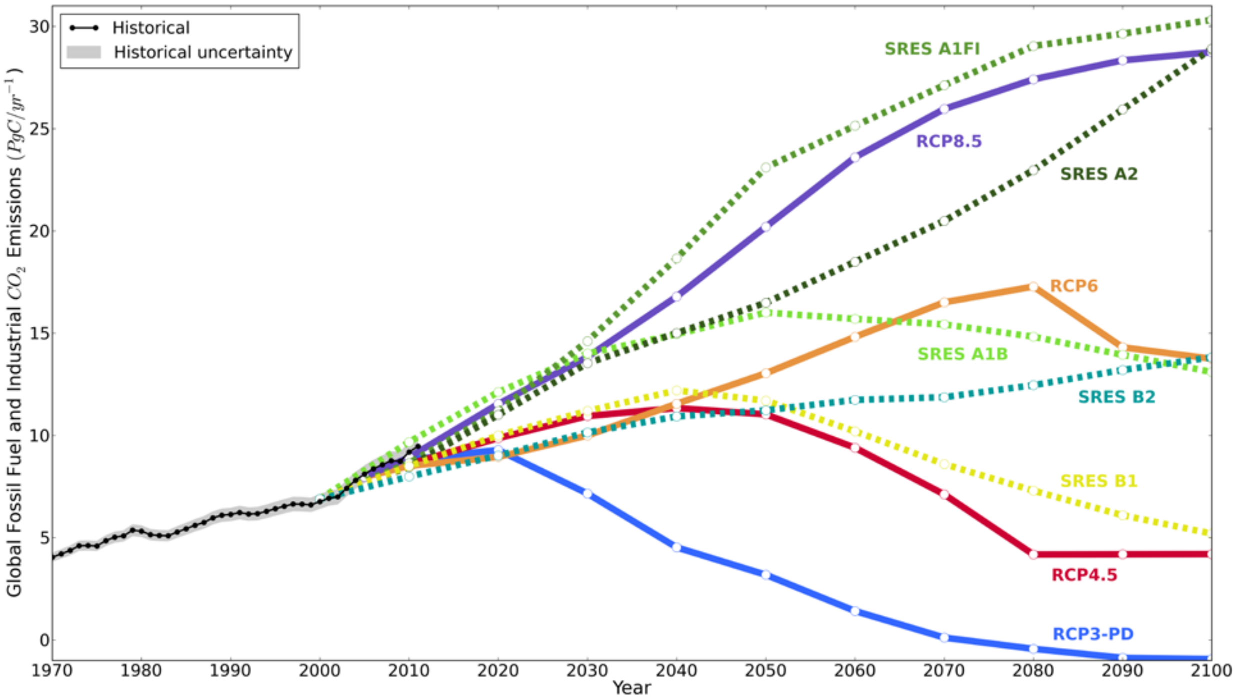

Figure A1.1 Comparison of fossil fuel and industrial emissions of CO2 in the SRES and RCP scenarios, through the 21st century (Compiled from data from the Global Carbon Project, IPCC SRES, and IIASA RCP database).

Will it be possible to explain the differences between the SRES and RCP based climate scenarios?

Not really, because the RCP climate scenarios are being performed with different climate models (CMIP5) to the SRES (CMIP3) based climate scenarios, so it is not possible to say whether differences in projected changes are due to the use of different models or different emissions scenarios. Nevertheless, there is some recent work which indicates that global mean temperature projections at the end of the twenty-first century, spans a similar range for the SRES/RCP scenarios, but with important differences in the rates of warming between the two (Rogelj *et al*. 2012). This would clearly have relevance for questions relating to how soon certain key policy relevant thresholds may be exceeded. The differences between the SRES and RCP climate scenarios for change in global mean temperature are shown in figure A1.2.

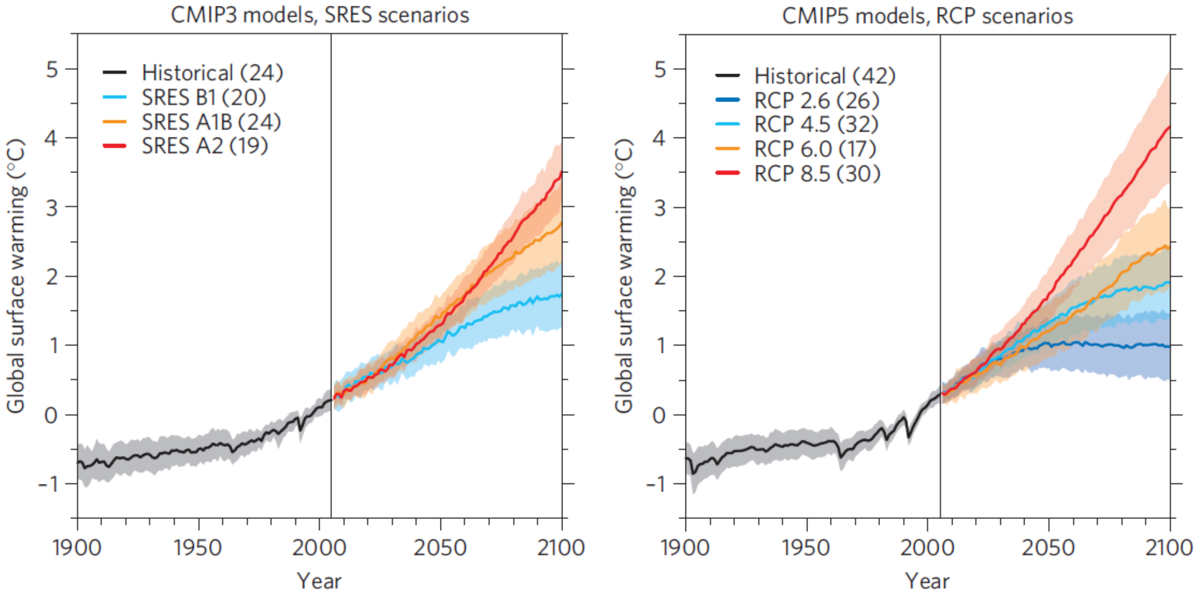

Figure A1.2 Comparison of global temperature change from SRES and RCP driven climate scenarios. *Source*: Knutti & Sedlacek (2012).

Appendix 2 Robust Decision Making Case Studies

RDM in practice: a quantitative and qualitative example
This appendix provides two examples of robust decision making being applied to adaptation problems, one taking a quantitative and the other a qualitative approach.

Case study one, a quantitative example: Southern California's Inland Empire Utilities Agency (IEUA) (Lempert & Groves 2010)

Problem definition

The Inland Empire Utilities Agency (IEUA), is a regional urban water utility in southern California, responsible for providing water and wastewater services to a population of 800,000 in Riverside County (Lempert & Groves 2010). In accordance with the Urban Water Management Planning Act, the IEUA is legally required to produce an Urban Water Management Plan (UWMP), every five years, which describes and assesses its ability to successfully meet the current and future demand for water over the next twenty years. Traditionally, these UWMPs have been developed on the basis of trends in historical climate data (thus assuming climate stationarity), and did not consider how climate change, and other factors may influence the success of this plan over time. With the growing importance of climate change, the IEUA invited the RAND Corporation, to collaborate with them on analysing how their plan may be affected by climate change. This study is reported in a paper by Lempert & Groves (2010).

The IEUA currently meets its water demands through a mix of groundwater sources, water import from Northern California, local rivers and streams, and a water recycling system. The region that the IEUA serves is currently experiencing rapid urban growth, which is projected to increase over the next twenty years, resulting in changes in land use from an agricultural region to industrial and planned residential developments. This urban growth is also accompanied by population growth, with the population projected to increase from the current 800,000 to in the region of 1.2 million by 2025 (Lempert & Groves 2010). Clearly, these changes in population number and land use will put greater strain on the demand for water, and changes in climate may place greater strain on the available supply of water. In order to obtain a better idea of how these changes in operating conditions may impact the UWMP, the RAND Corporation carried out a Robust Decision Making vulnerability-and-response-option analysis. This RDM analysis sought to answer the questions:

1. How would the existing plan perform under alternative plausible futures?
2. How might the plan be adapted to ensure future success in meeting the water demand of the inhabitants of Riverside County.

The RDM process had the following features:

Model used

Water planning simulation model called WEAP (Water Evaluation and Planning System), was used, and is available from http://www.weap21.org/

Model driving variables

1. Changes in monthly temperature and precipitation for the period 2000-2030, within plausible ranges based on values obtained from local variability and future trends from climate models.
2. Future water demand based on the water intensity of new housing stock.
3. Climate change induced declines in imported supplies.
4. Response of groundwater basin to urbanisation and the amount of precipitation that percolates into the groundwater basin.
5. Achievement of management strategies – delaying a recycling program, and groundwater replenishment goals.
6. Future costs – annual cost increases due to imported supplies, and efficiency achievements.

Ranges for these key variables were obtained via interviews with IEUA staff, apart from the management strategies, whose plausible values were obtained via surveys of the region's water managers, public officials, and interested public.

Performance criterion or vulnerability threshold

The IEUA defined a vulnerability threshold of $3.75 billion for total present value costs. Scenarios under which this performance goal was not satisfied (i.e. costs were greater than this threshold), were classed as strategy or policy failures.

RDM approach and results

Using this model set up, they sampled a wide range in and combinations of values of these driving variables, to generate a database containing 450 different scenarios, or plausible alternative futures. The current UWMP was then evaluated or 'tested' against these 450 scenarios, to see how successful it would be in meeting its performance goal of total costs less than $3.75 billion. Analysis of the results showed that there were a significant number of cases where higher costs would be incurred, and that of the six driving variables, a particular combination of three of these, were chiefly responsible for causing the vulnerability; these were 1) large declines in precipitation, 2) larger than expected impacts of climate change on the availability of imported supplies, and 3) reductions in percolation of precipitation into the groundwater basin.

These results persuaded the IEUA that there was the potential for a significant threat to their business objective (meeting the region's water needs), and that alternatives to the current plan should be sought, which might reduce this vulnerability. Eight alternative strategies were then tested against 200 of the 450 scenarios, and their performance analysed. These eight alternatives were composed from four different adaptation options:

1. Larger dry year yield (DYY) program and advancing the development of their water recycling program.
2. Replenishment (additional investment in storm water capture and groundwater replenishment facilities).
3. Implementation of water efficiency programs.
4. All three of the above in combination

These alternatives were either implemented in static or adaptive mode. In adaptive mode the strategies would be assessed every five years, and if new information showed that changes were needed alternative adaptation policies or pathways would be followed (an adaptation pathways approach). The results of this analysis are summarised in figure A2.1, which shows the relative performance of the different strategies, as the number of scenarios where a given strategy fails to meet the performance goal. From figure A2.1, it can be seen that all strategies that were adaptive were less vulnerable than the same strategy implemented in static mode, and that implementing all strategies or actions would result in the least vulnerable or most robust policy.

The task for the IEUA was then to decide which of these adaptation options they wanted to pursue, and they developed a measure of the level of effort involved to implement the various options. This resulted in the development of a tradeoff curve, where the effectiveness of the strategy is related to the level of effort involved in implementing the strategy.

This study highlights the benefits of adaptive policies, which require monitoring, and through which alternatives can be progressively adopted, as more is learnt about how the system functions.

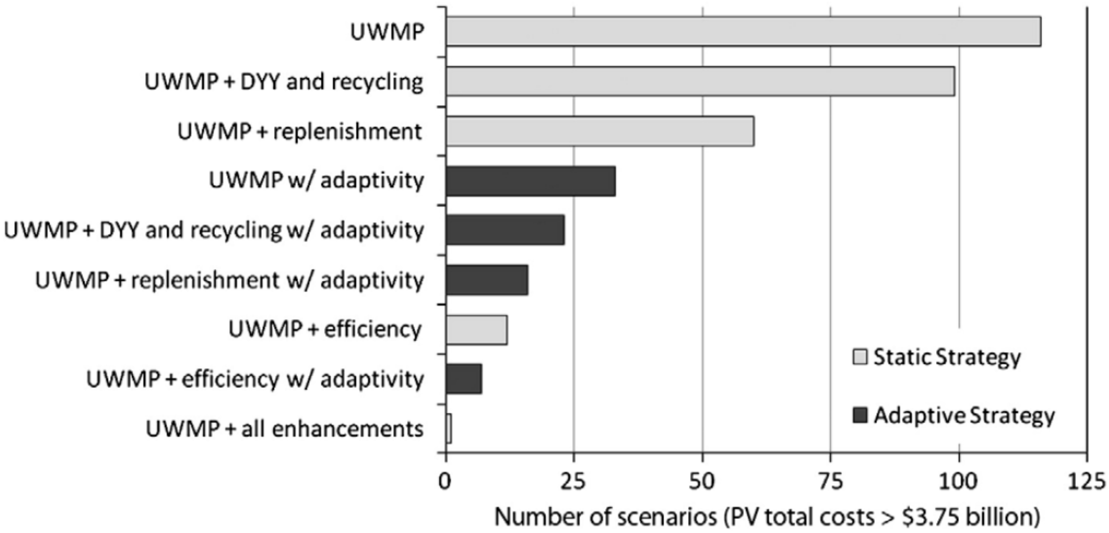

Figure A2.1 Number of future scenarios with present value (PV) total costs greater than $3.75 billion for nine strategies, the existing plan UWMP, and eight alternatives. (DYY refers to supply from a regional dry-year-yield groundwater storage program. UWMP is the Urban Water Management Plan. Adaptivity means that the performance of the strategy will be assessed every 5 years, and if changes are needed then these will be enacted) *Source*: Lempert & Groves (2010).

Case study two, a qualitative example: Canadian forest mountain pine beetle restoration (McDaniels et al. 2012)

Problem definition

Mountain pine beetle (MPB) infestations in pine forests of British Columbia, Canada, has been a major problem for over a decade, resulting in the death of significant percentages of pine trees. This clearly has major implications economically and socially, and the problem of MPB infestation, is known to be exacerbated by climate change. McDaniels *et al*. (2012), adopted a qualitative approach to robust decision making, in order to consider alternative forest management strategies, which would help clear or harvest, reforest, and rehabilitate areas covered with dead Lodgepole pine stands.

Robustness criterion: robustness defined as being reasonably likely to achieve objectives, over a range of uncertainties.

Model used

They developed a simple conceptual system model on the basis of understanding the key factors and how they interact with each other, and their impact on the multiple performance objectives that a forest management strategy might need to meet. This conceptual model was presented in the form of an influence diagram, which graphically displays the interdependencies between the different parts of the system, and how they are all connected to the decision context, of meeting the different performance objectives. This influence diagram is shown in figure A2.2.

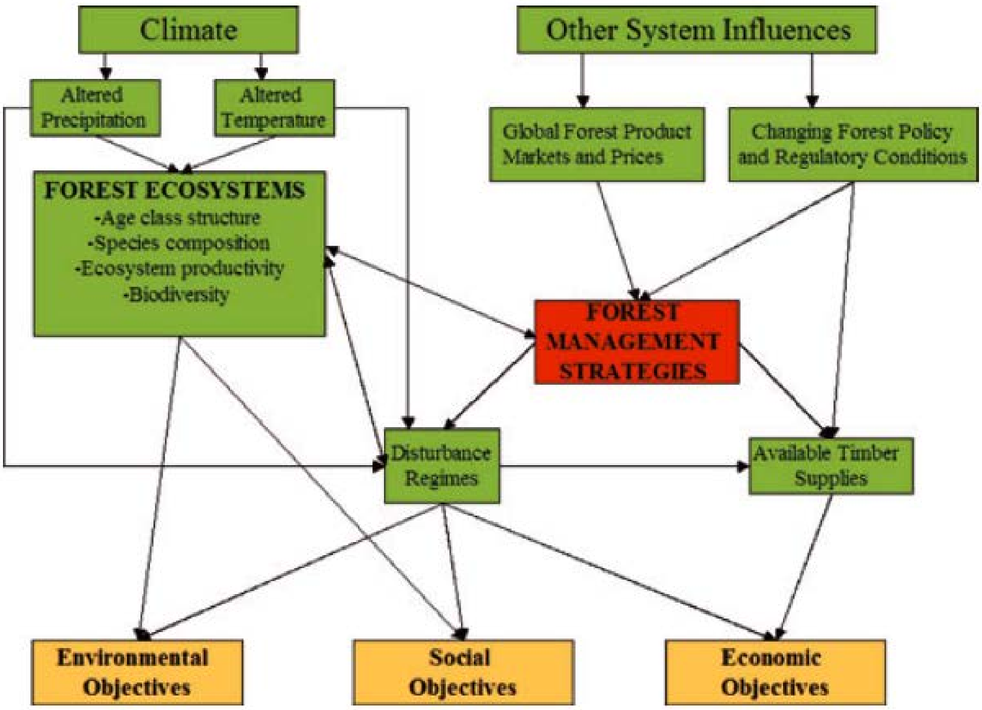

Figure A2.2 The influence diagram representing the conceptual model that was developed in support of this adaptation problem. *Source*: McDaniels *et al*. (2012).

Model driving variables

They explored the effect of uncertainty in the climate variables, seasonal temperature and precipitation, and the effect changes in these may have on the function of forest processes, and the implications this may have for the robustness of the different management strategies. They explored three different climate scenarios which were generated from 30 GCM simulations. The three scenarios were a no change scenario, and a low, and high scenario which represented the 10th and 90th percentile of the GCM simulations, respectively. These climate scenarios were developed for the short term i.e. the next 10-30 years, and over the longer term i.e. the next 30-100 years.

Performance objectives

The different management strategies were assessed according to three sets of performance criteria. These were:

1. Economic: strategies should maximise overall net economic value of the forest.
2. Social: strategies should maximise non-timber values, including cultural, spiritual, recreation, and aesthetic considerations; and minimise community fire risk.
3. Ecological: strategies should maximise ecosystem resilience – both terrestrial and aquatic.

RDM approach

Using the expert opinion of 14 regional forest management experts from academia, industry, government, consulting, and pest management, four different management strategies were assessed for their performance or robustness under the three different climate scenarios. The four management strategies were based on different levels of harvesting, silviculture practices e.g. species composition, and fire management practices. Two of these strategies were current management strategies, and two were alternative strategies.

This evaluation by the 14 experts took place during a half day workshop. The experts were then asked to assess the performance of the different strategies across the three different climate scenarios and over the short and long term. The performance of the alternative strategies were assessed in relation to the current or average performance of forest management over the last 20 years – the status quo, on each of the performance objectives.

In this evaluation experts were required to provide their judgment of how much better or worse each of the strategies would perform in relation to the status quo. This evaluation was done individually for all performance objectives over each climate scenario, for the short- and long-term. Experts were required to provide a three point estimate of performance which would encompass a range of uncertainty in their judgment. An example of an evaluation sheet which illustrates how these expert judgments were recorded is shown in figure A2.3. In addition to considering the climate scenarios, experts were also asked to consider how surprises unrelated to climate factors may emerge and how this may affect the strategies.

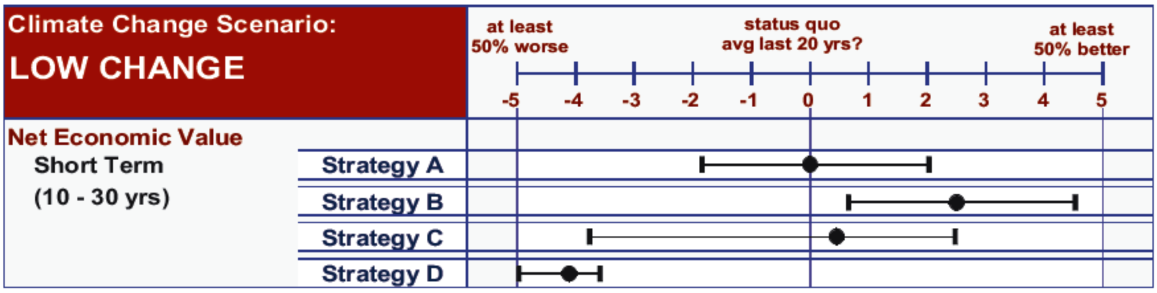

Figure A2.3 An example of an evaluation sheet for the four different strategies showing how the expert judgments of performance were recorded. *Source*: McDaniels *et al*. (2012).

Results

The worksheets from the experts were entered into a database and analysed, for each climate scenario. To determine the overall performance of the different strategies, the expert judgments for each strategy were averaged over the performance objectives, climate scenarios, and time periods. Results showed that the two alternative management strategies would be more robust to uncertain futures.

In performing this analysis, equal importance was assigned to each of the performance objectives. In reality however, it could be that a forest owner may place greater value on economic performance or ecological resilience. In order to assess the effect that increased importance of one performance objective over the others might have on the assessment of the most robust strategy, they carried out a sensitivity analysis, where a range of different weights were assigned to the different factors. This showed that in only one extreme case would a different strategy to the one selected based on overall performance, be more robust.

Conclusion

This case study shows that the RDM approach can also be successfully applied in a qualitative assessment, duly placing lesser demands on the resources needed to carry the work out.

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