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Chapter 2

Integrated Risk and Uncertainty Assessment of Climate Change Response Policies

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Chapter 2: Integrated Risk and Uncertainty Assessment of Climate Change Response Policies

Contents

Executive summary

The scientific understanding of climate change and its impacts over time has increased dramatically in recent years but there is still considerable uncertainty surrounding these projections. There is a growing recognition that today's policy choices are also highly sensitive to uncertainties associated with the actions of other decision-makers and technological learning.

In this framing chapter we explore the how the decision processes of different interested parties are affected by risk and uncertainty and suggest decision tools for improving policy choices. We highlight these issues by developing a taxonomy that focuses on the locus of decision-making and types of choices. Throughout the chapter we elaborate on these elements from a descriptive as well as from a normative perspective. In particular we ask how key stakeholders deal with risk and uncertainty (descriptive perspective) and contrast their behavior with formal models of choice and decision aids for dealing with uncertainty (normative perspective). We also examine the pros and cons of utilizing these models and decision aids to assist those making choices with respect to climate change policy. A significant portion of the chapter focuses on individual decision-making but we also consider how choices are made when the policy issue involves multi-agents such as international negotiations and agreements under uncertainty.

This chapter extends previous IPCC reports in two directions, topical and disciplinary. Rather than focusing solely at the global level, climate-related decisions are expanded to all decision-making loci, as shown in Table 2.1. Compared to AR4 where judgment and choice were primarily framed from a normative perspective based on rational economic models, this chapter reviews the psychological and behavioural literature on perceptions and responses to risk and uncertainty. The positive features and challenges of utilizing more formal choice models and decision aids from the practitioners' perspective are also discussed. Finally, the expansion in the scope of the challenges associated with developing risk management strategies for climate change policies requires reviewing a much larger body of published research than was considered in AR4.

Two developments make decision under risk and uncertainty in the climate policy context a challenging problem. (1) The range and number of interested parties who are involved in climate policy choices have increased substantially in recent years, and (2) the governance forums within which climate policies are developed and enforced has widened. At the same time, the number of different policy instruments under active discussion has also increased. Once limited to a focus on cap and trade and carbon taxes, these policy options now extend to instruments such as feed-in tariffs or quotas for renewable energy and investments in research and development.

Climate change policies can be categorized by *locus of decision-making* and *types of choices.* These two elements are the basis of a taxonomy that links the Introduction and the Framing chapters (Part I) with the Transformation Pathway chapters (Part II) and Policies and Institutions chapters (Part III). The relevant decision makers engaged in determining a specific choice will be confronted with specific risks and uncertainties that stem from numerous sources, such as imprecise data on previous system states from which to parameterize forecasting models, and disagreements between experts on how to interpret evidence. A decision, such as *setting a climate change target,* requires international cooperation. The choices will be sensitive to risks and uncertainties with respect to *climate impacts and damage* costs, as well as uncertainty with respect to technologies that are available now and in the future. In contrast, *livelihood and lifestyle choices* made at the individual or household level rely on very different information, much of it tacit rather than explicit.

The presence of risk and uncertainty can also affect the processes by which interested parties make decisions: how much time, effort and computation do they devote to examining specific problems they face? Do they focus their analysis on the most likely outcomes from their choices or those that may be unlikely to occur but would result in severe consequences? Do they employ systematic algorithms for aiding their decision-making process or rely on their intuition and experience-guided judgment? Do they plan ahead with the intent of possibly changing their decisions in the future when they can reexamine the uncertainties associated with the likelihood and consequences of specific outcomes?

The structure of this chapter is based on a risk management approach to developing climate change policies. The **problem formulation phase** characterizes the specific climate change policies that are being considered and how they affect the actions and well being of different stakeholders. Actions can be taken at a global level such as setting climate targets, or at national levels such as legislating a carbon tax, or at the household level such as adopting energy efficiency measures.

Risks frequently are perceived in ways that differ from expert judgments, posing challenges for climate risk communication. These perceptions can enrich expert assessments by incorporating psychological dimensions (e.g., dread, controllability) that contribute to or detract from the well being of those at risk. With respect to making choices under uncertainty, decision makers tend to focus on short time horizons, utilize simple heuristics in choosing between alternatives, and selectively attend to subsets of goals and objectives. ***Section 2.2*** provides empirical evidence on behavioural responses to risk and uncertainty by examining the types of biases that influence individuals' perception of the likelihood of an event (e.g., availability, learning from personal experience), the role that emotional, social and cultural factors play in influencing the perception of climate change risks and mental models that individuals utilize in making decisions

A wide range of methodologies and decision aids have been developed for evaluating options and making choices in a systematic manner, even when probabilities are difficult to characterize and/or outcomes are uncertain. These tools, detailed in **Section 2.3,** encompass variants of expected utility theory, decision analysis, cost-benefit or cost-effectiveness analyses that are implemented in integrated assessment models (IAMs). Decision aids include adaptive management, robust decision-making and uncertainty analysis techniques such as structured expert judgment and scenario analysis.

Climate change policies are an exercise in risk management. ***Section 2.4*** examines how the outcomes of particular options are sensitive to risks and uncertainties. It reports on literature that considers the selection of long-term global greenhouse gas emissions and concentration or temperature targets. It examines alternative investment pathways by considering the costs of benefits of mitigation measures or meeting the concentration or temperature targets while at the same time dealing with uncertainty from the social planner's perspective. It also examines the literature on structuring international negotiations and paths to reach agreement, and the design and implementation of regional, national, and sub-national policies and the relevant instruments for meeting specific climate change goals. It also examines risk management strategies for gaining public support for adaptation and mitigation policies at various levels of governance as well as making the adoption of technologies more attractive economically.

The developing countries will suffer the most from impacts of climate change, namely increased drought and flooding, sea level rise, and dysfunctional and unpredictable weather patterns. Methodologies to aid decision-making in the face of uncertainties require intensive use of resources and data that are beyond their reach. Risk plays a central role in the displacement of governmental responsibility to private sector and NGO actors in developing countries. At the national level, improved communication and better infrastructure are needed. Mitigation and adaptation measures have to be flexible enough to deal with the uncertainties posed by climate change while satisfying resource and budget constraints.

Key Findings from Chapter 2

- Across a wide range of policy situations, uncertainty is sometimes a reason to wait and learn before taking a particular action, and sometimes a reason to take the action and learn later (**high confidence**). Waiting and learning is desirable when external events are likely to generate new information of sufficient importance as to suggest the planned action to be unwise (**high confidence**).

- When taking the uncertainty associated with the link of emissions and climate change impacts into account the effect of uncertainty depends on the decision criterion chosen. If this link involves irreversibilities, thresholds, strong nonlinearities, and/or fat tails, then investments in mitigation technologies should be enhanced (**high confidence**). If one sets a temperature target, inclusion of climate uncertainty leads to decade-scale earlier recommendations for investments into mitigation technologies (**medium confidence**).
- A number of institutional and governance factors stand in the way of effective climate change risk management in the developing countries **(high confidence**). This could change if these countries developed a more transparent, predictable and effective civil service to stimulate investments in renewable energy generation capacities. To date the literature examining the effects of risk and uncertainty on climate policy development unique to developing countries is thin.
- The selection of climate change policies and their implementation can benefit from examining the perceptions and responses of relevant stakeholders **(high confidence)**. Decision-makers often misperceive climate change risks and consequences and place weight on short-run outcomes when making mitigation or adaptation investment decisions (**high confidence).** Policy instruments that acknowledge these behavioral biases and spread upfront investment expense over time, so the short-term benefits exceed the costs, are likely to perform quite well **(high confidence)**.
- There has been a growing body of experience with policies to shift investment, in particular in the energy sector, away from high carbon fuels. Empirical study of the outcomes suggests that investment behavior is very sensitive to perceived risks; among the instruments that provide a positive expectation of profit for low carbon investments, those that also minimize the variance in profit have stimulated investment more rapidly than those that create conditions under which variance is high **(high confidence)**.

The chapter concludes with a discussion of future research directions. Here e we suggest studies that enable us to understand more fully the decision processes utilized by individuals when making choices involving climate change. There are opportunities to improve risk communication (e.g. using simulation, games and movies) coupled with incentives, standards and regulations for improving choices under risk and uncertainty. There is also a need to characterize fat tails in empirical distributions, systematically examine cross-cultural differences in human perception and reaction to uncertain climate change and examine special problems facing developing countries in dealing with risk and uncertainty with respect to climate change policies.

2.1 Introduction

This chapter is concerned with how to interpret and deal with uncertainty and risk in developing and implementing policies and decisions aimed at mitigating or reducing climate change and its impact

Uncertainty denotes a cognitive state of incomplete knowledge that results from a lack of information and/or from disagreement about what is known or even knowable. It has many sources ranging from quantifiable errors in the data to ambiguously defined concepts or terminology to uncertain projections of human behavior.[1] Probability density functions and parameter intervals are among the most common tools to represent uncertainty. The IPCC AR5 uncertainty guidance notes (MD Mastrandrea et al., 2011) summarizes a list of tools for representing uncertainty highlighted in the Appendix to Chapter 2.

Risk refers to the potential for adverse effects on lives, livelihoods, health status, economic, social and cultural assets, services (including environmental), and infrastructure due to uncertain states of the world. To the extent that there is a detailed understanding of the characteristics of a specific event, experts will normally be in agreement regarding estimates of the likelihood of its occurrence and its resulting consequences. Risk can also be subjective in the sense that the likelihood and outcomes are based on the knowledge or perception that a person has about a given situation. There may also be risks associated with the outcomes of different climate policies, such as the harm arising from a change in regulations, as discussed in Sect 2.4.

In this framing chapter, we consider ways in which uncertainty and risk can affect the process and outcome of strategic choices in responding to the threat of climate change. On the one hand, scientific understanding of climate change and its impacts, along with how these affect policy choices, have increased dramatically in recent years. Yet the uncertainties associated with key components of the climate system are still within the same order of magnitude (see IPCC, AR4, WGI, SPM, Fig 5). On the other hand, the literature reveals a growing recognition that today's policy choices are highly sensitive to uncertainties not having to do with the climate system, such as the actions of other decision-makers and technological learning .

The focus of the chapter is characterizing how key stakeholders deal with risk and uncertainty and suggesting ways to improve their decision-making processes as a basis for formulating and evaluating risk management strategies. More specifically we examine ways of integrating behavioral features with more formal decision tools and aids to develop climate policies that have a good chance of achieving their desired impact.

2.1.1 A Taxonomy for Framing Decision Making Loci and Types of choices

The range and number of interested parties who are involved in climate policy choices have increased substantially in recent years. There has been a widening of the governance forums within which climate policies are developed and enforced at the global level (David G. Victor, 2011), across multiple networks within sovereign states (Andonova et al., 2009; MJ Hoffmann, 2011), and at subnational jurisdictions such as states, provinces, counties, and cities (Moser, 2007; H. Bulkeley, 2010). There has also been an expansion in the types of individuals and groups playing a visible role in influencing government policy. These include civil society (Cabré, 2011), finance and business organizations(Meckling, 2011), and high profile people concerned with the issue of climate, such as actors and celebrities (Boykoff and Goodman, 2009). At the same time the number of different policy instruments under active discussion has also increased, from an initial focus on cap and trade and carbon tax instruments (MJ Hoffmann, 2011; M. Betsill and MJ Hoffmann, 2011), to now include

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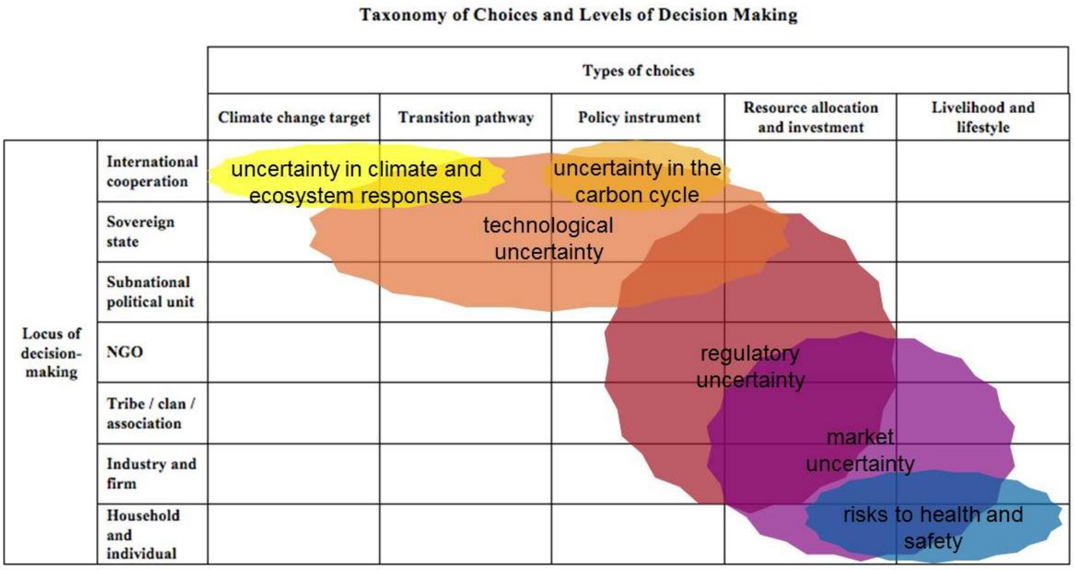
[1] Traditionally, 'uncertainty' refers to the *incompleteness* of the knowledge or belief in a probability measure. However, the climate community has developed a more inclusive definition over the past decades that is summarized here and also highlighted by the IPCC AR5 Uncertainty Guidance Notes.

instruments such as feed-in tariffs or quotas for renewable energy (Wiser et al., 2005; Mendonça, 2007), investments in research and development (Sagar and Van der Zwaan, 2006; H. De Coninck et al., 2008; Grubler and Riahi, 2010), or reform of intellectual property laws(Dechezleprêtre et al., 2011; Percival and A Miller, 2011).

To add structure to the current situation, we introduce a taxonomy for evaluating climate change policies shown in Table 2.1 that focuses on the locus of decision-making (that ranges from a global perspective to individuals and households) and the types of choices to be made (climate change targets, transition pathways, etc.). The cells in this table include specific choices or decisions to be taken, some of which are discussed below. Table 2.1 also suggests some of the main uncertainties that are relevant to policy- and decision-makers, contingent on where the taxonomy their own choices are located. These uncertainties appear most prominently in the literature that we review later in this chapter, notably in section 2.4. That literature, for example, distinguishes between uncertainties in the *climate system and ecosystem responses* that largely determine the choice of climate change target and characterize the nature of the transition pathway towards a stabilization of the climate system, and uncertainties in *the carbon cycle* that are important for choosing between different policy instruments. The purpose of the Table is thus to illustrate how the uncertainties that have been empirically identified as relevant vary according to what types of choices analysts have focused their attention.

Table 2.1. In the background is a taxonomy of the types of choices encountered in the climate policy arena (columns) and their locus of decision-making (rows), showing the wide variety of choice situations involve interested parties. Superimposed on the matrix are uncertainties that the literature has identified as influencing types of choices.



A decision, such as *setting a climate change target,* requires international cooperation at the global level in which case the choices will be sensitive to risks and uncertainties with respect to *climate impacts and damage* costs, as well as uncertainty with respect to technologies that are available now and or in the future. In contrast, *livelihood and lifestyle choices* made at the individual or household level rely on very different information, much of it tacit rather than explicit. For example, a household considering whether to invest in household energy efficiency, or even to locate their household in a city or near a power plant, may consider issues of health and safety, and may be insensitive to climate uncertainty or the long-term benefits and costs of energy efficient technologies. The choice of climate policies can thus be viewed as an exercise in risk management (Kunreuther, Heal et al in press).

Following the three framing chapters, the remainder of this report will consider a number of different policy problems and decision-making environments that will highlight the role that this taxonomy plays with respect to the policy choices and the decision-making units involved in determining what measures should be adopted. The particular risks that decision-makers are seeking to manage will change as one examines different types of choices.

To illustrate the taxonomy in Table 2.1 consider the following two examples:

Example 1: Choices Involving Climate System Uncertainty

Certain choices such as determining whether to impose a ***carbon tax*** (and if so at what level) are affected by ***climate system uncertainties*** that require a characterization of the tail of the distribution. There are also different interpretations of the same risk phenomena, such as the degree to which climate change is controllable because it is due to human actions that produce greenhouse gas (GHG) emissions, in contrast to the degree to which climate change is caused by natural phenomena that are largely uncontrollable. AUTHORS TO REVIEWER: Reference required

These high stake choices are negotiated globally by stakeholders at the sovereign state level. They require collectively binding decisions if there is to be a change in the status quo. Should there be agreement on a course of action, it will have an impact on decisions at the firm, individual and household level.

There will also be challenges in implementing specific policies and monitoring behavior by countries and stakeholders at lower decision-making loci. In order to examine alternative policies and strategies at those levels, one needs to understand the perceptions, values and goals of the key decision makers to predict their actions and their interactions as they negotiate specific policies.

There is also an opportunity to utilize decision tools, such as cost-benefit analysis or cost-effective analysis, to determine the relative merits of setting different climate targets and imposing carbon taxes of different magnitudes. To the extent that fat tails impact on these analyses, one might turn to cost-effectiveness analysis and robust decision making to address this problem.

Example 2: Choices Involving Technological, Market and Regulatory Uncertainty

The transition pathway towards a stabilization of climate will depend crucially on the availability of negative emissions technologies. Indeed, many of the results presented in Chapter 6 are based on the assumption that, by the end of the century, it will be possible to have large amounts of negative emissions; however the amount available is highly uncertain and will depend on the impact of these technologies on human activities and the ecosystem.

Choices such as whether a country should encourage the developments of new forms of energy are impacted by ***technological uncertainty***. More specifically technological uncertainty raises questions regarding the types of ***policy instruments*** a sovereign state should utilize and what ***transition pathway*** it should follow (two types of choices listed in Table 2.1). Governments could encourage investments in low carbon technologies or new technologies by deciding on what type of policy instrument they would like to utilize. They could provide direct incentives such as subsidizing research and development (R&D) of these technologies or indirect incentives s by guaranteeing a price at which the output of the new technology is purchased, as Germany did with respect to encouraging solar energy (Bhandari and Stadler, 2009).

The decision to support new technological development is normally made by the national government (i.e. at the sovereign state level). However, it involves stakeholders at other decision-making loci such as the affected firms and industries, NGOs and the general public who are faced with ***regulatory and market uncertainty***. For example, will the government maintain a price guarantee for the output of a new technology over the entire time period that it originally agreed upon? The success of the actions by the government will depend on the ***resource allocation and***

investment choices by firms and the ***livelihood and lifestyle*** decisions by households and individuals who have to determine whether or not to invest in these new technologies (two other types of choices listed in Table 2.1).

2.1.2 Key uncertainties and risk that matter for climate change response policies

Risks and uncertainties can stem from numerous sources such as a lack of understanding about a system's dynamic properties and imprecise data on previous system states from which to parameterize forecasting models. For complex systems with multiple interactions between the different elements, some uncertainties are likely to be irreducible over the time horizon for which decisions are taken. In many cases, scientific research and investments in data gathering can reduce uncertainty, though disagreements between scientists or experts on how to interpret evidence, called *conflict uncertainty* (Patt, 2007) or *judgment uncertainty* (O'Reilly et al., 2011) adds another dimension. For example, there has been concern by climate scientists with the impact of the melting of the Greenland and Antarctic ice sheets on sea level rise (SLR). Experts have different views on climate drivers and possible short- and long-term evolution of the ice sheets. This makes outcomes, such as SLR, more difficult to predict than had been previously believed (Bamber and WP Aspinall, 2012). In making decisions under conditions of risk and uncertainty one needs to consider the likelihood and costs associated with making Type I and Type II errors. An example of a Type I error in the context of climate change would be that scientists hypothesize that climate change occurs because of anthropogenic emissions of greenhouse gases (GHGs) when this hypothesized causal relationship actually exists. A Type II error would occur if scientists assume no such causal relationship exists, when, in fact, it does.

The effects of Type I and Type II errors will depend on the particular type of uncertainty. With respect to a Type I error in characterizing a causal relationships in the climate system when they do not exist, is likely to lead to an overinvestment in climate mitigation measures while a Type II error, would result in under-investment. Consider the above example. Suppose scientists hypothesize that the temperature will increase by 1 degree C by the year 2050 because climate change occurs due to GHG emissions and a set of policies labelled Strategy A are implemented to deal with this situation. What is the likelihood of this hypothesis **not** being true (Type I error) and the consequences of implementing Strategy A? Suppose, on the other hand, scientists hypothesize that no relationship exists between GHG emissions and climate change so Strategy B is implemented. What is the likelihood of this hypothesis **not** being true (Type II error) and the consequences of implementing Strategy B? On a more general note, tools like decision analysis can be utilized to determine the likelihood and consequences of different strategies as a function of the degree of climate change over a specific time period as highlighted in Sect 2.3 in the context of households adopting energy efficiency measures.

The presence of risk and uncertainty can also affect the processes by which interested parties make decisions. How much time, effort and computation do they devote to examining specific problems they face? Do they focus their analysis on the most likely outcomes from their choices or those that may be unlikely to occur but would result in severe consequences? Do they employ systematic algorithms for aiding their decisions-making process or rely on their intuition and experience-guided judgment? Do they plan ahead with the intent of possibly changing their decisions in the future when they can reexamine the uncertainties associated with the likelihood and consequences of specific outcomes? Section 2.4 discusses how responses to these questions affect the decision outcomes.

The uncertainties and risks that matter for policy choices are classified into four areas:

- *Uncertainties in climate and ecosystem responses.* The large number of key uncertainties with respect to the climate system is discussed in WG I. These uncertainties cascade into even greater uncertainties with respect to climate impacts. The costs of those impacts on society are examined in Working Groups II and III. More generally one needs to examine a wider possible range of potential climate impacts than previously considered when developing risk management strategies.

- *Technological uncertainty.* Deployment of technology is often a critical aspect of both adaptation and mitigation policies. In the adaptation area, infrastructure technologies, such as levees and floodwalls, can protect residents from climate impacts due to sea level rise. Irrigation systems can protect farmers against the consequences of drought on their crop yields. In the mitigation area technologies that would allow for negative emissions (as for example bioenergy coupled with a carbon capture and sequestration system) would have a crucial role in the attainment of temperature stabilization target. However, it is currently uncertain how these technologies will perform, how expensive they will be, and their potential impact on other economic sectors, on the ecosystem, on health, or food security. The technologies that governments will support, private sector firms and entrepreneurs will invest in and the general public will embrace are likely to be sensitive to these uncertainties.

Uncertainty in the carbon cycle and its impacts. The state of the environment and society in the future are likely to be determined in large part by factors other than climate change. The previous two assessment reports have characterized a possible set of development pathways. A new set of shared socio-economic pathways (SSPs) has been developed for AR5 that highlight uncertainty and the range of scenarios with respect to possible future greenhouse gas emissions, the costs and benefits of emissions reductions, and people's vulnerability to impacts of climate change (Kreigler et al., 2010).

- *Regulatory risk, market and negotiation uncertainty.* Climate policy for adaptation and especially mitigation is concerned with creating incentives for private sector actors to alter their investment behaviour that may also require well-enforced regulations. Many incentive and regulatory instruments, such as taxes, carbon markets, subsidies, or technology quotas, are relatively new policy developments, and their effectiveness is still being tested and evaluated (VH Hoffmann, 2007). Policy makers' choices about which interventions to favour are likely to be sensitive to uncertainties generated by differences in assumptions and models characterizing the 12ehaviour of the system.

- There is also uncertainty with respect to the dynamics of international climate negotiations. The resulting outcomes depend on how individual negotiators perceive the preferences of the parties across the table (Plous, 1993), the predictions they make about the future, and the techniques they utilize to motivate their counterparts and their own constituents to undertake specific actions. `

2.1.3 A Risk Management Framework for Structuring the Chapter

The structure of this chapter is based on a risk management approach to developing climate policies illustrated in Figure 2.1. It highlights the importance of problem formulation with the taxonomy (Table 2.1) providing an organized structure. It then focuses on how individuals, groups and organizations perceive and make choices under conditions of risk and uncertainty with respect to climate change issues (*descriptive analysis)* and the role that more formal decision aids and models can play in improving choices under uncertainty and risk (*normative analysis)*. The bottom box in the figure indicates that climate change policies with respect to both adaptation and mitigation measures are an exercise in risk management. We label this phase of the process *prescriptive analysis* for the following reason: by considering both descriptive analyses of stakeholder behaviour and normative models for making informed choices, one increases the chance of implementing specific climate change policies and having them achieve their desired outcomes.

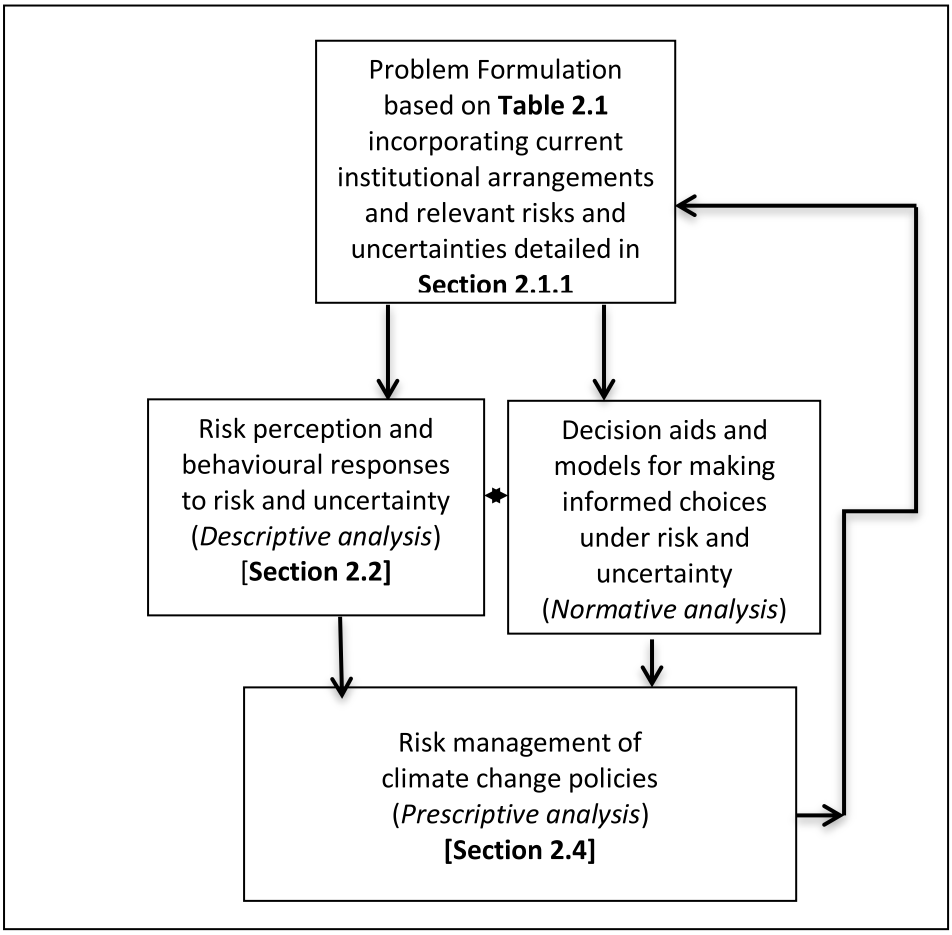


Figure 2.1. A Risk Management Framework

We now briefly discuss each of these elements and summarize a set of key points discussed in the other sections of the chapter.

Problem Formulation. The problem formulation phase characterizes specific policy choices being considered with respect to climate change and the relevant stakeholders involved with the final decision. The decisions s can be taken at a global level such as setting climate targets, or at lower levels such as legislating a carbon tax or developing strategies for households such as adopting energy efficiency measures or investing in ways to reduce future flood losses given the likelihood of sea level rise.

In this phase of the process one characterizes the institutional structure and the policy process that guide and restrain collective activities of a group, society, or international community concerned with the specific problem characterized as *risk governance* by Klinke and Renn (2012). One also needs to consider risks and uncertainties associated with the nature of climate and the performance of the different policy tools delineated in Sect 2.1.2. The goals and objectives of the different stakeholders given their values and immediate and long-term agendas will also play a role in developing climate policies in the face of risk and uncertainty.

Risk Perception and behavioural responses to risk and uncertainty. A large empirical literature has revealed that individuals, small groups and organizations often do not make decisions in the analytic or rational way envisioned by normative models of choice in the economics and management science literature. Risks frequently are perceived in ways that differ from expert judgments, posing challenges for climate risk communication and response. There is a tendency to focus on short time horizons, utilize simple heuristics in choosing between alternatives, and selectively attend to subsets of goals and objectives.

To illustrate, the voting public in some countries may have a wait and see attitude toward climate change, leading their governments to postpone mitigation measures designed to meet specified climate targets (J. D. Sterman, 2008; Dutt and C Gonzalez, 2011). A coastal village may decide not to undertake measures for reducing future flood risks due to sea level rise (SLR) because they focus unduly on the next few years by not discounting the future exponentially. They may also not take into account SLR in their decision-making processes because it is below their threshold level of concern. They are thus likely to conclude that the uncertain short-term benefits do not justify the upfront investment costs of the proposed adaptation measures.

Decision models and aids for making informed choices. A wide range of decision tools have been developed for evaluating alternative options and making choices in a systematic manner even when probabilities are difficult to characterize and/or outcomes are uncertain. The relevance of these tools for making more informed decisions depends on how the problem is formulated and framed, the nature of the institutional arrangements and the interactions between stakeholders that characterizes risk governance (Hammond et al., 1999; PJH Schoemaker and Russo, 2001).

In developing a global climate target for the year 2050, integrated assessment models (IAMs) combined with an understanding of the negotiation process may prove useful to delegates intent on justifying the positions of their country at a global climate conference. Governments debating the merits of a carbon tax may turn to cost-effectiveness analysis to justify their positions. They may need to take into account that firms who utilize formal approaches, such as decision analysis, may not reduce their emissions if they feel that they are unlikely to be penalized because the carbon tax will not be well enforced. Households may find the expected utility model or decision analysis to be useful tools for evaluating the costs and benefits of adopting energy efficient measures given the risk and uncertainty associated with climate change and the trajectory of future energy prices.

Risk management of climate change policies Climate change policies are a challenge for risk management. The policies will be influenced by how the problem is formulated and the key risks and uncertainties delineated in **Sect 2.1.2**. Policies should be designed to take into account how the relevant stakeholders perceive risk and their behavioural responses to uncertain information and data *(descriptive analysis).* The policy design process also needs to consider the methodologies and decision aids for systematically addressing issues of risk and uncertainty (*normative analysis)* that suggest strategies for improving outcomes at the individual and societal level (*prescriptive analysis).*

The way climate change is managed will impact on the problem formulation phase as shown by the feedback loop in Figure 2.1. The nature of this feedback can be illustrated by the following examples. Individuals may be willing to invest in solar panels if they are able to spread the upfront cost over time through a long-term loan. Firms may be willing to promote new energy technologies that provide social benefits with respect to climate change if they are given a grant to assist them in their efforts. National governments are more likely to implement carbon markets or international treaties if they perceive the short-term benefits of these measures to be greater than the perceived costs. Education and learning can play key roles in how climate change is managed through a reformulation of the problem and reconsideration of policies for managing the risks and uncertainties associated with climate change.

2.1.4 Storyline for the Chapter

The key points of the chapter can be summarized as follows:

- As indicated by the taxonomy depicted in **Table 2.1** there is an evolving set of choices related to climate policy made by different constellations of decision makers in the face of risks and uncertainties associated with natural systems, the techno-economic system, other political processes and the impacts of all of these on social systems.

- ***Section 2.2*** provides empirical evidence on behavioural responses to risk and uncertainty by examining the types of biases that influence individuals' perception of the likelihood of an event (e.g., availability, learning from personal experience), the role that emotional, social and cultural factors play in influencing the perception of climate change risks and mental models that individuals utilize in making decisions. The section also addresses the ways people respond to different forms of risk communication and how short-term horizons and impatience impact on actions that individuals take in response to the risk and uncertainties of climate change.

- ***Section 2.3*** delineates formal methodologies and decision aids for analyzing risk and uncertainty when individuals, households, firms, communities and nations are making choices that impact their own well-being and those of others. These tools encompass variants of expected utility theory, decision analysis, cost-benefit or cost-effectiveness analyses that are implemented in integrated assessment models (IAMs). Decision aids include adaptive management, robust decision-making and uncertainty analysis techniques such as structured expert judgment and scenario analysis. The chapter highlights the importance of selecting different methodologies for addressing different problems.
- ***Section 2.4*** reviews findings that are both descriptive and normative that could support or undercut particular policies or decisions. It examines how the outcomes of particular options, in terms of their efficiency or equity, are sensitive to risks and uncertainties. It starts with risk management decisions at the broadest possible geographical and temporal scales, namely the selection of long-term global greenhouse gas emissions and concentration targets and stabilization pathways for dealing with uncertainty from the social planner’s perspective and the structuring of international negotiations and paths to reach agreement. The section also examines risk management strategies for gaining public support for adaptation and mitigation policies at various levels of governance as well as making the adoption of technologies more attractive economically under conditions of risk and uncertainty. These include pathways to achieve pre-selected targets, the specific instruments and interventions designed to do so, and the effects of risk and uncertainty on private sector investments of many kinds.

Box 2.1. Risk and Uncertainty in the Developing Countries

COMMENTS ON TEXT BY TSU TO REVIEWER: Boxes highlighting further LDC-specific issues are included in other chapters of the report (see chapter sections 1.3.1, 6.3.6.6, 7.9.1, 8.9.3, 9.3.2, 10.3.2, 11.7, 12.6.4, 16.8) and a similar box may be added to the Final Draft of chapters, where there is none in the current Second Order Draft. In addition to general comments regarding quality, reviewers are encouraged to comment on the complementary of individual boxes on LDC issues as well as on their comprehensiveness, if considered as a whole.

In the developing world, the least developed countries (LDCs) are recognised as the world’s poorest and weakest ones, with Small Island Developing States (SIDS) possibly disappearing in the future due to sea-level rise caused by climate change. LDCs are especially vulnerable to these risks because of their dependence on resources that are sensitive to changes in climate such as agriculture, fisheries and other sectors that constitute the livelihood of rural populations. Together, these countries will experience larger impacts of climate change, namely increased droughts and floods, sea level rise, and dysfunctional and unpredictable weather patterns (UN, 2009). These changes will have adverse effects on food, water, security, increase incidences of temperature-influenced diseases and pests (Shah et al.) and lead to failure to attain the millennium development goals (MDGs) ranging from the eradication of extreme poverty and hunger, achieving universal primary education to ensuring environmental sustainability (UN, 2000).

There are established links between total energy use and each of the MDGs such that actions geared towards improving energy access could be especially beneficial with regards to drinking water, hunger reduction, and poverty alleviation (Nussbaumer, 2013). The use of traditional cook stoves leads to indoor air pollution caused by solid biomass burning(Riahi et al., 2012). If there is no electricity for lighting, this may lead to the inability of children to go to school (Doll and Pachauri, 2010). Policies to encourage low-carbon development offer an opportunity to share in the benefits of green growth, address a range of existing market and government failures in the developing world, and provide low-cost options for global emissions reductions. For example, there are synergies between rural electrification, poverty alleviation and emissions reduction in the forestry and agriculture sectors (Bowen and S. Fankhauser, 2011).

A number of institutional and governance factors stand in the way of effective climate change risk management in the developing countries. There is a need for these countries to institute a more transparent and effective civil service, one that operates predictably and without corruption in order to stimulate investments into renewable energy generation capacities (Komendantova et al., 2012). There is a lack of experience with insurance (Patt et al., 2010), dearth of data and analytic capacity, and widespread decentralization (Sharma et al., 2012). Although there are several adaptation initiatives by developing countries to overcome these problems, for example, the implementation of National Adaptation Programmes of Action (NAPA) (UNFCCC, 2011) and the development of micro insurance in India and Malawi (Gine, 2009), the literature examining the effects of risk and uncertainty on climate policy development unique to developing countries is thin (UN, 2009).

In developing countries, the type of choices about livelihood and lifestyle that are most likely to increase future vulnerability involve sector-level planning (e.g. water, fisheries, and agriculture), regulation and, most commonly, long-lived infrastructure (Ranger and Garbett-Shiels, 2011). For example, an urban planning policy choice that promotes the building of new homes in areas exposed to flooding may place people, property and infrastructure at risk (Ranger and Garbett-Shiels, 2011).

With respect to the locus of decision making in Table 2.1, NGOs and Tribal/Clan community-based associations have a strong presence and influence on how these choices are made. A local association may assemble groups in order to clarify the risks and uncertainties faced by these communities and decide on an agricultural system of crop rotation to retain soil fertility, or shifting cultivation to preserve the nutritious state of farmlands. NGOs and Tribes/Clans involving group participation can be beneficial in communicating and reducing risk. For example, research in African LDCs has shown that people may understand probabilistic information better when it is presented to and discussed in a group where members have a chance to discuss it (Patt et al., 2005; Roncoli, 2006). More generally, the risks and uncertainty associated with climate change has shifted governmental responsibility to the local community and NGO actors (Rayner, 2007) . The choice of governmental policies on risk is affected by the political culture and regulatory policy style of the country or region (Rayner, 1993). Resource or budget allocation and investment constraints may lead policy-makers to postpone decisions today. The downside of this delay is it prevents opportunities for learning and improvement, and may increase future vulnerabilities to climate change or even lead to expensive retrofits in the future. In this regard, current investments by external entities like the World Bank in Bangladesh and Sub-Saharan Africa have helped these nations to better adapt and mitigate trends in climate change (Ikeme, 2003; World Bank, 2010). There will be challenges of water management in the Himalayan-Ganga region in the decades ahead due to water scarcity (Gyawali, 2001).

Adaptation and mitigation measures will require building flexibility to cope with the uncertainties and risks. In this regard the New Rice for Africa (NERICA) project has helped to improve food security and reduce reliance on rice imports in countries experiencing crop failure due to excessive drought by producing early maturing, higher yielding, and drought-tolerant, pest resistant crops to prepare for such as disaster (UNFCCC, 2006) .Effective planning and public institutions, access to markets and credit, and sustainable natural resource management can also build capacity to respond effectively to these weather-related events (DFID, 2010).

One needs to also recognize that measures undertaken by developing countries may be counterproductive In the face of risk and uncertainty, (Wright and Fulton, 2005). For example, the Delhi government has adopted large-scale investments in compressed natural gas (CNG) that can reduce pollution but may create greater greenhouse gas emissions (Wright and Fulton, 2005). This is likely to occur when one considers the upstream methane losses along pipelines (Roychaudhary, 2008).

In summary, developing countries need to eradicate the institutional and governance factors that present hurdles for the effective management of climate change risks. For example, increase in transparency in civil service will stimulate additional foreign direct investments into renewable energy generation capacities. Implementing policies that will improve energy access will go a long way toward achieving the MDGs, because policies that support low-carbon development also help to address market and government failures. New insurance initiatives coupled with an education process so that farmers and others at risk see the new for this form of protection, more data gathering and storage capabilities will be critical for developing countries to hedge against climate change risks. In consonance with recent risk mitigation literature, the management of climate risks in LDCs will depend critically on creating resilience by promoting resource diversification, poverty alleviation, and improvements to healthcare systems.

FAQ 2.2 What are the challenges facing developing countries in dealing with risk and uncertainty as it affects climate policies?

The developing countries are especially vulnerable today because of their dependence on resources that are sensitive to changes in climate such as agriculture, fisheries and other sectors that constitute the livelihood of rural populations. These changes will have adverse effects on food, water, security, increase incidences of temperature-influenced diseases and pests and lead to failure to attain the millennium development goals (MDGs) ranging from the eradication of extreme poverty and hunger, achieving universal primary education to ensuring environmental sustainability.

Actions geared towards improving energy access could be especially beneficial with regards to drinking water, hunger reduction, and poverty alleviation. Policies to encourage low-carbon development offer an opportunity to share in the benefits of green growth, and provide low-cost options for global emissions reductions. For example, there are synergies between rural electrification, poverty alleviation and emissions reduction in the forestry and agriculture sectors.

A number of institutional and governance factors stand in the way of effective climate change risk management in developing countries. There is a need for these countries to institute a more transparent and effective civil service to stimulate investments into renewable energy generation capacities. Resource or budget constraints may lead policy-makers to postpone decisions today. The downside of this delay is it prevents opportunities for learning and improvement, and may increase future vulnerabilities to climate change.

Adaptation and mitigation measures will require building flexibility to cope with the uncertainties and risks. New insurance initiatives coupled with an education process so that farmers and others at risk see the need for this form of protection will help hedge against climate change risks such as drought and severe flooding. More generally, the management of climate risks in developing countries will depend critically on creating resilience by promoting resource diversification, poverty alleviation, and improvements to healthcare systems.

2.1.5 What is new on risk and uncertainty in AR5

Chapter 2 in AR4 WGIII was also on risk and uncertainty and served as a framing chapter. It illuminated the relationship of risk and uncertainty to decision making and reviewed the literature on catastrophic or abrupt climate change; irreversibility and catastrophic or abrupt changes. It examined three pillars for dealing with deep uncertainties: precaution, risk hedging, and crisis prevention and management. The report also described) how risk and uncertainty was handled by IPCC authors, provided a typology of uncertainty, and summarized the discussions in the economic literature about the limits of cost-benefit analysis in situations of deep uncertainty.

Since the AR4 publication, risk and uncertainty has remained a key aspect of climate policy-related decisions. Regarding technological risks, the adverse impact of bio fuels on food prices, the nuclear disaster in Fukushima, and the growing extraction of shale gas, have come to the forefront. In AR4 the climate science community offered probability density functions of climate sensitivity that is global in scope. A critical change since the AR4 has been a growing number of studies that have considered and compared additional sources of risk and uncertainties, such as regulatory and technological risks, and how these may play an influence on governance strategies. As the number of political jurisdictions implementing climate policies has increased, there are empirical findings to supplement the modelling-based studies on the effects of such risks. At the local level adaptation studies using scenario-based methods have been developed (ECLRC, 2011).

This chapter extends previous reports in two main directions, topical and disciplinary. Rather than focusing solely at the global level, this chapter expands climate-related decisions to all decision-making loci, as shown in Table 2.1. Compared to AR4 where judgment and choice were primarily framed in rational-economic terms, this chapter reviews the psychological and behavioural literature on perceptions and responses to risk and uncertainty. The pros and cons of alternative methodologies and decision aids from the point of view of practitioners are also considered in the chapter.

Finally, the expansion in the scope of the challenges associated with developing risk management strategies in relation to AR4 requires reviewing a much larger body of published research. To illustrate this point, the chapter reviews and classifies more than 50 publications on decision-making under uncertainty with respect to Integrated assessment models (IAMs), the first time such a detailed examination of this literature has been undertaken.

2.2 Perceptions and behavioural responses to risk and uncertainty

In designing mitigation and adaptation measures to reduce climate change risks one needs to recognize both the strengths and limitations of decision makers in dealing with risk and uncertainty. One also needs to frame the problem and provide decision aids and tools so that they can make more informed choices. Decision makers often have insufficient or inaccurate information about climate risks and effective responses that can and needs to be addressed by public education. However, cognitive and motivational barriers appear to be equally or more important, and to date have been less acknowledged (EU Weber and Paul C. Stern, 2011).

A large body of cognitive psychology and behavioural decision research has distinguished between two modes of thinking that go back to William James (1878) and Heidegger (1962) and have recently been described by Kahnemann (2003; 2011) as *System 1* and *System 2*:

- System 1 operates automatically and quickly with little or no effort and no sense of voluntary control and uses intuitive responses (e.g., emotional reactions) and simplified heuristics or rules often based on personal experience with events and their consequences.

- System 2 initiates and executes effortful and intentional mental operations as needed, including simple or complex computations or formal logic.

Even though the operations of these two processing systems do not map cleanly onto distinct brain regions and the two systems often operate cooperatively and in parallel (EU Weber and E.J. Johnson, 2009; Kahneman, 2011) argues that the distinction between System 1 and 2 helps to make clear the tension in the human mind between the automatic and largely involuntary processes of intuitive decisions and the effortful and more deliberate processes of analytic decisions.

Many of the simplified decision rules that characterize human judgment and choice under uncertainty reflect more automatic System 1 processes. Such decisions are guided by past experiences, expectations, beliefs, and goals of the decision maker. Decisions made this way often lead to reasonable outcomes and require much less time and effort than a more detailed analysis of the trade-offs between options. If one takes into account the time and attention and processing-capacity constraints facing human decision makers, these decisions may be the best we can do left to our own devices (Simon, 1957).

System 1 processes are utilized in making choices not only by the general public, but also by technical experts such as insurers and regulators (H. Kunreuther, Pauly, et al., 2013) as well as by groups and organizations (Cyert and J March, 1963; Cohen et al., 1972; Barreto and Patient, 2013).

These processes work well, when the personal experience of decision makers reflects the distribution of outcomes and events (Feltovich et al., 2006).

System 1 processes are most susceptible to biases for choices that have probabilistic outcomes involving rare events and long time horizons (EU Weber, 2011), contexts in which personal experience is inherently limited. In this respect, System 1 behaviour can be particularly problematic for risks such as increased flooding and storm surge possibly due to sea level rise or rapid climate change, or a surge in fossil fuel prices as a result of an unexpected political conflict (Taleb, 2007) where there is limited or no personal experience or historical data and considerable disagreement and uncertainty among experts in their risk assessments.

A key feature of behaviour under System 1 is a tendency to focus on the short run when thinking about possible responses to climate change risks and their associated uncertainties. This happens when consumers for whom upfront investments in energy efficient technology or solar energy sources are not an economic constraint nevertheless focus too much on these costs and fail to incorporate future savings sufficiently (H. Kunreuther and EU Weber, 2013). At a policy level, policy makers can be overly focused on short-term public reluctance to change, and not enough on long-term improvements in public welfare~~.~~

The more formal models and tools described in Section 2.3 require the decision maker to utilize System 2 and make deliberative choices in a systematic manner and recognize the need to develop long-term strategies for dealing with the consequences of climate change and mitigation and adaptation actions. Implementing these proposed solutions may be difficult in the face of System 1 perceptions and reactions to climate risks. **Section 2.5** suggests future research needs to facilitate the design of long-term policies that have a chance of being implemented today by recognizing and counteracting the human tendency to focus on more immediate consequences.

It has been argued (Charlesworth and Okereke, 2010) that conventional policy approaches and tools (e.g., cost-benefit analysis) are incapable of generating satisfactory responses to such uncertain events with potentially catastrophic consequences. It has also been suggested that alternative decision frameworks (e.g., the precautionary principle or other decision rules that do not depend on precise specification of probabilities, such as the incremental adaptive approach of robust decision models (R. J Lempert et al., 2004), discussed in ***Section 2.3****,* should therefore be utilized in developing risk management strategies for climate change(Charlesworth and Okereke, 2010; H. Kunreuther, G. Heal, et al., 2013).

2.2.1 Risk perception of uncertain events

This subsection focuses on perceptions of and reactions to the uncertainties and risks of climate change and climate change responses. Empirical evidence from social science research reveals that perceptions and reactions depend not only on external reality but also on the observers' internal states, needs, and cognitive and emotional processes that characterize System 1 behavior. More specifically, evidence from cognitive, social, and clinical psychology indicates that risk perception is influenced by two types of System 1 behaviour that often overshadow the analytic processes associated with System 2 behavior (see EU Weber, 2006):

1. *the use of associative processes* such as connections between objects or events contiguous in space or time, resembling each other, or having some causal connection (Hume, 2000; EU Weber, 2006)

2. *the use of affective processes,* i.e., processes influenced by emotions such as fear, dread or anxiety).

The human processing system maps both the uncertainty and the adversity components of risk into affective responses and represents risk as a feeling rather than as a statistic (GF Loewenstein et al., 2001). These associative and affective processes are automatic, fast, and available to everyone from an early age, as is typical of System 1 thinking, and get informed and shaped by personal experience over time. Analytic assessments of risk such as probability estimation, Bayesian updating, and formal logic, must be taught and require conscious effort as is typical of System 2 thinking. Psychological research over the past decade has documented the prevalence of affective processes in the intuitive assessment of risk, depicting them as essentially effort-free inputs that orient and motivate adaptive behaviour, especially under conditions of uncertainty (Finucane et al., 2000; GF Loewenstein et al., 2001; Ellen Peters et al., 2006).

Two important psychological risk dimensions have been shown to influence people's intuitive perceptions of health and safety risks across numerous studies in multiple countries (P. Slovic, 1987). The first factor, dread risk, captures emotional reactions to hazards like nuclear reactor accidents, or nerve gas accidents, i.e., things that make people anxious because of a perceived lack of control over exposure to the risks and because consequences may be catastrophic. The second factor, unknown risk, refers to the degree to which a risk (e.g., DNA technology) is perceived as new, with unforeseeable consequences and with exposures not easily detectable.

Perceptions of the risks associated with a given event or hazard are also strongly influenced by personal experience and therefore can differ between individuals as a function of their location, history, and/or socio-economic circumstances (Figner and EU Weber, 2011). Whereas personal exposure to adverse consequences increases fear and perceptions of risk, familiarity with a risk without adverse consequences can lower perceptions of its risk. This suggests that greater familiarity with climate risks, unless accompanied by alarming negative consequences, could actually lead to a reduction rather than an increase in the perceptions of its riskiness (Kloeckner, 2011). Seeing climate change as a simple and gradual change from current to future values on variables such as average temperatures and precipitation may make it seem controllable, e.g., the non-immediacy of the danger seems to provide time to plan and execute responses (EU Weber, 2006).

2.2.1.1 Learning from personal experience vs. statistical description

Learning from statistical descriptions requires an understanding of numerical estimates of probability and outcomes and the use of System 2 processes to make deliberative decisions. Learning about uncertain events from repeated personal experience, be they adverse weather events or possible outcomes of different climate risk mitigation or adaptation responses, capitalizes on the automatic, effortless, and fast associative and affective processes of System 1 ((EU Weber et al., 2004). For many people this is the preferred way of thinking and learning about climate uncertainty (Marx et al., 2007).

Learning from personal experience is well predicted by reinforcement learning models (EU Weber et al., 2004). Such models describe and predict the general under-concern about low-probability high-impact climate risks on part of the general public (C Gonzalez and Dutt, 2011). These learning models also capture the volatility of the public's concern about climate change as reflected by opinion polls over time due to the overweighting of recent events. The Pew Research Center (2009) poll found that while 84% of scientists said the earth was getting warmer because of human activity such as burning fossil fuels, only 49% of non-scientists in this U.S. representative sample held this view. The small number of studies to assess climate change risk perceptions in developing countries find similar variability in concern over time, though generally higher levels of concern, probably reflecting greater experience of vulnerability (Vignola et al., 2012).

Most people do not differentiate very carefully between weather, climate (average weather over time), and climate variability (variations in weather over time). People confound climate and weather in part because they have personal experience with weather and weather abnormalities but little experience with climate, and thus substitute weather events for climate events (Whitmarsh, 2008). This confound as has been observed in the United States (Bostrom et al., 1994; Cullen, 2010) and in Ethiopia (BBC World Service Trust, 2009).

Judging climate change from personal experience of local weather abnormalities can easily distort risk judgments, reducing belief in climate change during abnormally cold winters (Li et al., 2011). On the other hand, people's experience can make climate a more salient issue. For example, changes in the timing and extent of freezing and melting (and associated effects on sea ice, flora, and fauna) have been experienced since the 1990s in the American and Canadian Arctic and especially indigenous communities (Laidler, 2006), leading to increased concern with climate change because traditional prediction mechanisms no longer can explain these (Turner and Clifton, 2009).

People's expectations of change (or stability) in climate variables also affect their ability to detect trends in probabilistic environments. For example, farmers in Illinois were asked to recall salient growing season temperature or precipitation statistics for seven preceding years (EU Weber, 1997). Farmers who believed that their region was undergoing climate change recalled temperature and precipitation trends consistent with this expectation, whereas farmers who believed in a constant climate, recalled temperatures and precipitations consistent with that belief. Recognizing that beliefs shape perception and memory, provides insight into why climate change expectations and concerns vary between segments of the U.S. population groups with different political ideologies (A. Leiserowitz et al., 2008).

The evidence is mixed when we examine whether individuals learn from past experience with respect to investing in adaptation or mitigation measures that are likely to be relatively cost-effective. Even after the devastating 2004 and 2005 hurricane seasons in the United States, a large number of residents in high-risk areas had still not invested in relatively inexpensive loss-reduction measures, nor had they undertaken emergency preparedness measures (Goodnough, 2006). Surveys conducted in Alaska and Florida, regions where residents have been exposed more regularly to physical evidence of climate change, show greater concern and willingness to take action (Assessment, 2004; A. Leiserowitz and Broad, 2008; Mozumder et al., 2011).

A recent study of a representative sample of the Britain public assessed perceptions and beliefs about climate change and behavioural intentions to reduce personal energy use to reduce greenhouse gas emission among individuals who had experienced recent flooding in their local area or had not (Spence et al., 2011). Concern about climate change was greater in the group of residents who had experienced recent flooding. Even though the flooding was only a single and local data point, this group also reported less uncertainty about whether climate change was really happening than those who did not experience flooding recently, illustrating the strong influence of personal experience.

Other studies fail to find a direct effect of personal experience with flooding generating concern about climate risks (Whitmarsh, 2008). On the other hand, they find that personal experience with ill health as the result of air pollution affects perceptions of and behavioural responses to climate risks (Bord et al., 2000; Whitmarsh, 2008), with the air pollution experience creating stronger pro-environmental values. Myers et al. (2012) looked at the role of experiential learning versus motivated reasoning among highly engaged individuals and those less engaged in the issue of climate change. Low-engaged individuals were more likely to be influenced by their perceived personal experience of climate change than by their prior beliefs, while those highly engaged in the issue (on both sides of the climate issue) were more likely to interpret their perceived personal experience in a manner that strengthens their pre-existing beliefs. The authors conclude that place-based climate change education strategies that highlight local impacts of climate change in a manner that can be experienced first-hand hold considerable potential to help people come to understand the issue in a manner more consistent with the state-of-the-science.

Indigenous traditional climate change knowledge contributions from Australia (Green et al., 2010), African (Orlove et al., 2009), the Pacific Islands (Lefale, 2009), or the Arctic (Gearhead, 2009) derive from accumulated and transmitted experience and focus mostly on predicting seasonal or interannual climate variability. Indigenous knowledge can supplement scientific knowledge in geographic areas with a paucity of data (Green and Raygorodetsky, 2010) and can guide knowledge generation that reduces uncertainty in areas that matter for human responses.

2.2.1.2 Availability

People often assess the likelihood of an uncertain event by the ease with which instances of its occurrence can be brought to mind, a mechanism called availability by (Tversky and Kahneman, 1973). The use of availability as a heuristic and its connection to differences among groups, cultures, and nations in responses to climate change risks is discussed by (Cass R. Sunstein, 2006). Availability is strongly influenced by recent personal experience and can lead to an underestimation of low probability events such as extreme weather (frosts, flooding, or droughts) before they occur and their overestimation extreme events have occurred. The resulting availability bias can explain why individuals purchase insurance after a disaster has occurs and cancel their policies several years later, as observed for earthquake and flood insurance (H. Kunreuther et al., 1978; Michel-Kerjan et al., 2012)

2.2.1.3 Other factors influencing perceptions of climate change risks

Climate change is a complicated phenomenon with a few climate drivers causing multiple hazards (Kempton, 1991; Bostrom et al., 1994) NRC, 2010). Mental models of causal connections between concepts or variables help people with their finite processing capacity comprehend complex phenomena. Non-scientists' mental models about climate change have been shown to diverge from those of climate scientists (Kempton, 1991; Bostrom et al., 1994). When climate change first emerged as a policy issue, people often confused it with the loss of stratospheric ozone resulting from releases of chlorofluorocarbon. As the "ozone hole" issue has receded from public attention, this confusion has become less prevalent (Reynolds et al., 2010). Instead, greenhouse gases are often wrongly equated with more familiar forms of pollution, with the incorrect inference that "the air will clear" soon after emissions are reduced (John D. Sterman and Sweeney, 2007). Most greenhouse gases continue to warm the planet for decades or centuries after they are emitted (Solomon et al., 2009).

There are also motivational challenges to a systematic processing of data on climate risks and the uncertainty about climate change, its physical and social consequences, and potential responses because people do not like to deal with negative events (S O'Neill and Nicholson-Cole, 2009). They also dislike being in environments over which they have no control (Langer, 1975). Many of the uncertainties associated with climate change are large and potentially irreducible. Experts often disagree in their predictions that can give rise to a feeling that climate change is an uncontrollable risk. This may lead people to minimize or deny climate risks for emotional reasons (Swim et al., 2010). This desire to deny the existence of climate change can be utilized by vested interests, who in the US and UK have funded organized campaigns to manufacture uncertainty and generate doubt in climate change or its anthropogenic origin (Oreskes and Conway, 2010). Providing the public with better advice on effective ways to mitigate and/or adapt to climate risks is an important policy function that will reduce the tendency to deny and ignore the risk (T. Dietz et al., 2013).

Motivated cognition is the label for a tendency to bias interpretation of facts to fit a version of the world we wish to be true, especially when existing uncertainty provides a cover or excuse (Kruglanski, 1999). Motivated cognition and the strategic use of uncertainty in the face of growing evidence of climate risks help explain increased polarization in attitudes and beliefs about climate change in the US (Pew, 2010) and UK (Whitmarsh, 2011) along ideological lines.

Mitigation or adaptation responses that provide solutions to existing or future climate risks require tradeoffs with respect individual and social goals, such as whether to continue use of familiar and reliable energy sources or to invest in energy efficient technologies and the impact of these alternative transition pathways with respect to economic growth and development, a reduction in GHG emissions and associated climate change, and changes in livelihood and lifestyle, types of choices specified in Table 2.1. People’s reluctance to acknowledge the need for tradeoffs has been documented in situations far less consequential than climate change and has been shown to give rise to simplifying decision rules such as lexicographic models that eliminate choice options (Payne et al., 1988). Politicians and policy makers frequently take off the table policy options that they perceive will reduce immediate economic growth, such as strategies for mitigating climate change. This behavior impairs efficiency because it reduces the opportunity for welfare-increasing tradeoffs (Anderson & Bows, 2010).

2.2.2 Risk communication challenges

If the uncertainties associated with climate change and its future impact on the physical and social system are not communicated accurately, the general public may misperceive them (Corner and Hahn, 2009). Krosnick et al. (2006) found that perceptions of the seriousness of global warming as a national issue depended on the degree of certainty of respondents as to whether global warming is occurring and will have negative consequences and their belief that humans are causing the problem and have the ability to solve it. Accurately communicating the (un)certainty in both climate risks and policy responses is therefore a critically important challenge for climate scientists and policymakers (N Pidgeon and B. Fischhoff, 2011).

People respond to uncertainty in qualitatively different ways depending on whether the possible outcomes are perceived as favorable or adverse (Smithson, 2008). Favorable uncertainty does not arouse concern, but unfavourable uncertainty does. The significant time lags within the climate system and a focus on short-term outcomes lead many people to incorrectly believe global warming will have only moderately negative impacts. This view is reinforced because adverse consequences are currently experienced only in some regions of the world or are not easily attributed to climate change. For example, despite the fact that “climate change currently contributes to the global burden of disease and premature deaths” (IPCC, 2007) relatively few people make the connection between climate change and human health risks .

One challenge is how to facilitate correct inferences about the role of climate change as a function of extreme event frequency and severity. Many parts of the world have seen increases in the frequency and magnitude of heat waves and heavy precipitation events (IPCC, 2012), leading a large majority of Americans to believe that climate change exacerbated extreme weather events (A. Leiserowitz et al., 2012).That said, the perception that the impact of climate change is neither immediate nor local persists (A. Leiserowitz et al., 2008) leading many to think it rational to advocate a “wait-and-see” approach to emissions reductions (Anthony Leiserowitz, 2007; J. D. Sterman, 2008; Dutt, 2011).

2.2.2.1. Individual differences in numeracy

Individual and group differences in cognitive abilities and the use of different cognitive and affective processes have additional implications for risk communication, suggesting that it may help to supplement the verbal probability labels recommended by current IPCC policy with numeric probability ranges (David V. Budescu et al., 2009). Patt and Dessai (2005) also show that IPCC TAR probability words are interpreted by decision makers in inconsistent and often context-specific ways, a phenomenon with a long history in cognitive psychology (Wallsten et al., 1986; EU Weber and Hilton, 1990). These context-specific interpretations of probability words are deep-rooted, as evidenced by the fact that the likelihood of using the intended interpretation of IPCC TAR probability words did not differ with level of expertise (attendees of a UN COP conference vs. students) or as a function of whether respondents had read the IPCC TAR instructions (Patt and S. Dessai, 2005).

Numeracy, the ability to reason with numbers and other mathematical concepts, is a particularly important individual and group difference in this context as it has implications for the presentation of likelihood information using either numbers (e.g., 90%) or words (e.g., “very likely” or “likely”)

(MD Mastrandrea et al., 2011) as well as different pictorial forms (e.g., graphs, box plots, diagrams) Individuals are likely to neglect time when it is factored into the likelihood judgment when the characterization of a person's possessions were in affect-rich terms (Ellen Peters et al., 2006; E. Peters et al., 2012) .Tying personal experience with climate variables has been shown to be effective in communicating the impact of probabilities (e,g,, of below-, about-, and above-normal rainfall in an El Nino year) to decision makers with low levels of numeracy, for example subsistence farmers in Zimbabwe (Patt et al., 2005). A further discussion of how to communicate scientific findings and their accompanying uncertainties appears in the Appendix.

To satisfy people's preference for concrete rather than statistical representations, scientists have started to translate probabilistic forecasts into a small set of scenarios (e.g., best and worst cases). Such scenario representation has been shown to facilitate strategic planning by professional groups such as military commanders, oil company managers, and policy makers (Bradfield et al., 2005; Schoemaker, 1995). Connecting IPCC scenarios more closely to probabilistic forecasts may be a useful exercise for future assessment reports.

These behavioural and cognitive science insights highlight some of the challenges facing scientists and policymakers in their efforts to communicate climate change risk effectively. A good summary of strategies to frame messages consistent with the communication goal and characteristics of the audience is provided by Moser (2010).

2.2.2.2 Effects of source of uncertainty

Uncertainty about the variables discussed in this chapter can derive from models (where different parameter values generate a range of predictions) or from disagreement among experts. While the two sources are equivalent from a normative perspective, they induce different responses. Patt (2007) showed, in the context of climate change adaptation decisions, that the latter source of uncertainty is often interpreted as a signal that the science behind the decision to be made is not sufficiently advanced, prompting decision makers to delay action until science can be more decisive, whereas model-based uncertainty is more likely to be seen as a reason to take action now.

2.2.2.3. Social amplification of risk

Hazards interact with psychological, social, institutional, and cultural processes in ways that may amplify or attenuate public responses to the risk or risk event. Amplification may occur when scientists, news media, cultural groups, interpersonal networks, and other forms of communication provide risk information. The amplified risk leads to behavioral responses, which, in turn, may result in secondary impacts such as the stigmatization of a place that has experienced an adverse event (RE Kasperson et al., 1988; Flynn et al., 2001) .

Ongoing research has demonstrated that the general public's overall concern about climate change is moderated, in part, by the amount of media coverage the issue receives as well as the personal and collective experience of extreme weather in a given place (A. Leiserowitz et al., 2012; Brulle et al., 2012). Overall levels of concern about climate change have been shown to vary over time (N Pidgeon and B. Fischhoff, 2011). To date climate change advocacy, such as lobbying public officials for climate change mitigation policies, is relatively rare. Roser-Renouf et al. (2013) built upon the work of Krosnick and colleagues (2006) by applying social cognitive theory to develop a model of climate advocacy. They found that that campaigns looking to increase the number of citizens contacting elected officials to advocate climate policy action should focus on increasing the belief that global warming is real, human-caused, a serious risk, and solvable. These four key elements, coupled with the understanding that there is strong scientific agreement on global warming (Ding et al., 2011), are likely to build issue involvement and support for action.

2.2.3 Factors influencing responses to risk and uncertainty

Individuals' perceptions and responses to risk and uncertainty are malleable. It matters, for example, how information about the risk is acquired and how it is framed (Lichtenstein and Paul Slovic, 2006;

EU Weber and E.J. Johnson, 2009). This section describes some widely observed choice patterns in people's decisions under risk and uncertainty that are typically the result of System 1 processes and are captured in descriptive models of choice under uncertainty such as prospect theory (Tversky and Kahneman, 1992) and over time where consequences are delayed (Laibson, 1997). While individual variation exists, these patterns of responding to potential outcomes, probabilities, and time delays have been found widely and across the levels of decision makers shown in Table 2.1 whether they by technical experts or laypersons.

2.2.3.1 Loss aversion

Loss aversion is an important property that distinguishes prospect theory (Tversky and Kahneman, 1992) from expected utility theory (J. von Neumann and Morgenstern, 1944). Prospect theory introduces a reference-dependent valuation of outcomes, with a steeper slope for perceived losses than for perceived gains. In other words, people are much more afraid of losing something than not getting something they want. This means that one can influence the value that decision makers place on a specific outcome by changing the way it is described or framed.

Loss aversion explains a broad range of laboratory and real world choices that deviate from the predictions of expected utility theory (Camerer, 2000). Letson et al. (2009) show that land allocation to crops in the Argentine Pampas, as an adaptation to existing seasonal-to-interannual climate variability depends not only on objective economic circumstances (e.g., whether the farmer is renting the land or owns it,), but also on individual differences in farmers' degree of loss aversion and risk aversion. Greene et al. (2009) show that loss aversion combined with uncertainty about future energy savings by investing in a more expensive but more fuel-efficient car can explain why consumers frequently appear to be unwilling to pay for energy-efficient technology that has positive expected value or expected utility.

Given loss aversion, the negative consequences of moving away from the status quo are weighted much more heavily than the potential gains, often leading the decision maker not to take action, referred to as the status quo bias (Samuelson and Zeckhauser, 1988). Loss aversion can be made to work in a positive way to increase public welfare, when welfare-increasing options (e.g., more energy-efficient technology) are made the default option in designing building codes when providing consumers with a choice as to whether they want to accept this option (Dinner et al., 2011).

2.2.3.2 Quasi-hyperbolic time discounting

Normative models suggest that future costs and benefits should be evaluated using an exponential discount function, i.e., a constant discount rate per time period, where the discount rate should reflect the decision-maker's opportunity cost of money (for more details see section 3.5.2). In reality, people discount future costs or benefits much more sharply and at a non-constant rate. Delays that prevent immediate receipt are viewed much negatively than a similar delay further into the future (G Loewenstein and Elster, 1992). Laibson (1997) characterized this pattern by a quasi-hyperbolic discount function, with two discounting parameters β (present bias) and δ (rational discounting) retains much of the analytical tractability of exponential discounting while capturing the key qualitative feature of discounting with true hyperbolas.

One explanation for this behavior is that future events (e.g. the prospect of coastal flooding 5 or 20 years from now) are construed abstractly, whereas events closer in time (the prospect of a major hurricane passing through town tomorrow) are construed more concretely (Trope and Liberman, 2003). The abstract representations of consequences in the distant future do not generate the more intense emotional reactions of present or near-present events and hence do not elicit similar concerns nor action (Dutt and C Gonzalez, in press). Many effective and efficient climate change responses like investments into household energy efficiency are not adopted because of decision makers' excessive discounting of future consequences so that the upfront cost of the measure dwarfs the long-term discounted expected benefits of adopting it.

2.2.3.3 Non-linear decision weights

The probability weighting function of prospect theory indicates that low probabilities tend to be overweighted relative to their objective probability unless they are perceived as being so low that they are ignored because they are below the decision-maker's threshold level of concern. (See Section 2.2.4.4.) Low probability events when knowledge about them is acquired by personal experience over time tend to be underweighted on average, but are overweighted immediately after the occur (EU Weber et al., 2004).

2.2.3.4 Ambiguity aversion

The Ellsberg paradox (Ellsberg, 1961) revealed that, in addition to being risk averse, most decision makers are also ambiguity averse, i.e., prefer well-specified probabilities (e.g., .5; risk) to ambiguous probabilities. Heath and Tversky (1991) demonstrated, however, that ambiguity aversion is not present when decision makers believe they have expertise in the domain of choice. In contrast to the many members of the general public who consider themselves to be experts in sports or the stock market, relatively few believe themselves to be highly competent in environmentally-relevant technical domains such as the tradeoffs between hybrid electric vs. conventional gasoline engines in cars so they are likely to be ambiguity averse. Farmer differences in ambiguity aversion have been shown to predict the adoption of new farming technology in Peru (Engle-Warnick and Laszlo, 2006) and in the USA (Barham et al., 2011).

2.2.3.5 Social norms and social comparisons

Other people's behaviour is informative, especially under conditions of uncertainty. "When in doubt, copy what the majority is doing" is not a bad rule to follow, most of the time, and can lead to social norms. (See Chapter 3, Section XX for a more detailed description of the rationale for these norms and Cialdini et al. on the effectiveness of providing such descriptive norms). The application of social norms to encourage investment in energy efficient products and technology is discussed in Section 2.4.4.3.

2.2.4 Behavioural responses to risk and uncertainty of climate change

We now turn to how the choice processes introduced in the previous section influence behavioural responses to the risk and uncertainty of climate change.

2.2.4.1 Cognitive myopia and selective attention

In the area of adaptation and the management of climate-related natural hazards such as flooding, an extensive empirical literature shows low adoption rates by the general public due to System 1 behavioural factors such as a focus on short-time horizons and misperception of the risk due to the availability bias. Thus few people living in flood prone areas voluntarily purchased subsidized flood insurance, even when it is offered at highly subsidized premiums under the National Flood Insurance Program (NFIP) when System 2 systematic analysis would have recommended buying this coverage. (H. Kunreuther et al., 1978). Analysis of the NFIP data base from 2001-2009 reveals that many homeowners who purchased flood insurance cancel their policies several years later, many of whom were required to have coverage as a condition for mortgage (Michel-Kerjan et al., 2012). It is likely that most of these individuals had not suffered any losses during this period and considered the insurance to be a bad investment. It is difficult to convince a person that the best return on an insurance policy is no return at all

In the context of climate change response decisions, energy efficient lighting technology (e.g., LEDs) commands a much higher purchase price than standard technology (e.g., incandescent bulbs). The higher upfront cost of the energy efficient technology is more than offset by the expected savings in energy costs over time; however, the delay in receiving these benefits which are viewed as uncertain and the high discount rates associated with these savings leads to environmentally less responsible choices (H. Kunreuther and EU Weber, 2013).

At a country or community level, the upfront costs of mitigating CO_2 emissions or of building seawalls to reduce the effects of sea level rises similarly loom large due to loss aversion, while the uncertain and future benefits of such actions are more heavily discounted than if one used an exponential function implied by normative models. Such accounting of present and future costs and benefits on the part of consumers and policy makers makes it difficult for them to justify these investments today and arrive at socially-responsible and long-term sustainable decisions.

2.2.4.2 Myopic focus on short-term goals and plans

Krantz and Kunreuther (2007) emphasize the importance of goals and plans as a basis for making decisions. In the context of climate change, protective or mitigating actions often require sacrificing short-term goals that are highly weighted in people's choices to meet more abstract, distant goals that are typically given very low weight. A strong focus on short-term goals (e.g., immediate survival) may have been appropriate in earlier times, but has less importance in the current environment where solutions to complex problems such as climate change require a focus on long time horizons. Weber et al. (2007) succeeded in drastically reducing people's discounting of future rewards by prompting them to first generate arguments for deferring consumption, contrary to their natural inclination to first focus on arguments for immediate consumption. A generally helpful tool to deal with uncertainty about future objective circumstances as well as subjective evaluations is the adoption of multiple points of view (RN Jones and Preston, 2011) or multiple frames of reference (De Boer et al., 2010), a generalization of the IPCC's scenario approach to an uncertain climate future.

2.2.4.3 Status-quo bias, reference points, and default options

Patt & Zeckhauser (2000) demonstrate that information about the status quo and other choice options can be presented to create an action bias with respect to addressing the climate change problem. More generally, choice architecture characterizes the process of changing the options and the context of a decision to overcome the pitfalls of System 1 processes without requiring decision makers to switch to effortful System 2 processing (Thaler and C. R. Sunstein, 2008).

Prospect theory (Tversky and Kahneman, 1992) provides the vehicle for applying the concepts of choice architecture by changing decision makers' reference points and hence the way outcomes get evaluated. Consider a farmer's decision as to whether or not to purchase insurance against a possible drought. By moving the farmer's reference point away from the status quo--its usual position--- to a possible large loss due to the occurrence of a drought, decision-makers will very likely choose the sure option of buying insurance at a relatively small premium rather than risking a severe loss from a future drought. Dutt (2011) provides additional examples of reframing for climate change related decisions, including acceptance of a carbon tax.

Another choice architecture tool comes in the form of behavioural defaults, i.e., recommended options that will obtain if no active decision is made to change from this pre-specified choice (EU Weber and E.J. Johnson, 2009). Defaults are viewed as a reference point so that decision makers normally stick with this option rather than change from it due to loss aversion (E. J. Johnson et al., 2007; EU Weber et al., 2007). Green defaults have been found to be very effective in lab studies involving choices between different lighting technology (Dinner et al., 2011), suggesting that environmental friendly and cost-effective energy efficient technology will find greater deployment if it shows up as the default option in building codes and other regulatory contexts. Green defaults are desirable policy options because they guide decision makers towards individual and social welfare maximizing options without reducing choice autonomy. In a field study, German utility customers adopted green energy defaults that persisted over time (Pichert and Katsikopoulos, 2008).

2.2.4.4 Threshold models of choice

Consistent with their desire not to make tradeoffs when choosing between alternatives, prior to a disaster people often perceive the likelihood of catastrophic events occurring as below their threshold level of concern, a form of System 1 behavior in the sense that one doesn't have to think about the consequences of a catastrophic event (Camerer and H. Kunreuther, 1989). The need to take steps today to deal with climate change presents a particular challenge to individuals who are myopic and utilize quasi-hyperbolic discount rates. They have a tendency to ignore long-term warnings by using a threshold model and deciding not take action now. The problem is compounded by the inability of individuals to distinguish between likelihoods that differ by one or even two orders of magnitude of 100 (e.g., between 1 in 100 and 1 in 10,000) (H. Kunreuther et al., 2001).

2.2.4.5 Risk protection by formal and informal institutions

Depending on their cultural and institutional context, people can protect themselves against worst-case and/or potentially catastrophic economic outcomes either by purchasing (H. Kunreuther, Pauly, et al., 2013) or by developing social networks that will help bail them out if or when such outcomes are realized or will cushion their fall (EU Weber and C Hsee, 1998). Individualist cultures favour formal insurance contracts, whereas collectivist societies make more use of informal mutual insurance by the cushion of social networks. This distinction between risk protection by either formal or informal means exist at the individual level but also at the firm level, e.g., the chaebols in Korea or the keiretsus in Japan (Gilson and Roe, 1993). Weber and Hsee (1998) observed such social network cushioning among Chinese MBA students.

2.2.4.6 Impact of uncertainty on coordination and cooperation

Adaptation and especially mitigation responses require coordination and cooperation between individuals, groups, or countries as shown in Table 2.1 for many of the choices associated with climate change. The resulting outcomes of different joint actions are either probabilistic or uncertain. Most theoretical and empirical work in game theory has been restricted to deterministic outcomes, though recent experimental research on two person prisoners' dilemma (PD) games shows that individuals are more likely to be cooperative when payoffs are deterministic than when the outcomes are probabilistic. A key factor explaining this difference is that in a deterministic PD game the losses of both persons will always be greater when they both do not cooperate than when they do. When outcomes are stochastic there is some chance that the losses will be smaller when both parties do not cooperate than when they do, even though the expected losses to both players will be greater if they both decide not to cooperate than if they both cooperate (H. Kunreuther et al., 2009).

In a related set of experiments, Gong et al. (2009) found that groups are less cooperative than individuals in a two person deterministic PD game; however, in a stochastic PD game, where defection increased uncertainty for both players, groups became more cooperative than they were in a deterministic PD game and more cooperative than individuals in the stochastic PD game. These findings have relevance to behaviour with respect to climate change where future outcomes of specific policies are uncertain. When decisions are made by groups of individuals, such as when delegations from countries are negotiating at the Conference of Parties (COP) to make commitments for reducing GHG emissions where the impacts on climate change are uncertain, there is likely to be more cooperation between the governments than if each country was represented by a single decision-maker.

Cooperation also plays a crucial role in international climate agreements. There is a growing body of experimental literature looks at individuals' cooperation when there is uncertainty associated with others adopting climate change mitigation measures. Tavoni et al. (2011) found that communication across individuals improves the likelihood of cooperation. Milinski et al., (2008) observed that the higher the risky losses associated with the failure to cooperate in the provision of a public good, the higher the likelihood of cooperation. If the target for reducing CO2 is uncertain, Dannenberg and Barrett (2012) show in an experimental setting that cooperation is less likely than if the target is well-specified.

FAQ 2.2. How can behavioural responses and tools for improving decision impact on climate change policy?

The choice of climate change policies can benefit from examining the perceptions and responses of relevant stakeholders. The empirical evidence indicates that decision-makers often misperceive climate change risks and consequences and tend to place undue weight on short-run outcomes when making mitigation or adaptation investment decisions. They are thus reluctant to adopt measures that reduce the impact of climate change.

Policy instruments that acknowledge these behavioral biases and shift upfront costs and delayed and uncertain benefits of actions (e.g., solar panel installations) in ways that build rather than work against human behavior have been shown to perform quite well. Consistent with loss aversion, investment risks have been shown to be of more concern to those funding projects than expected investment returns. Policy instruments that are most likely to stimulate new investments in particular technologies are ones that make those investments relatively risk free such as feed-in tariffs. They are likely to outperform instruments that focus on increasing the expected returns such as a carbon cap.

Human responses to climate change risks and uncertainties can also indicate shortcomings in normative models such as the failures to put adequate weight on worst-case scenarios or fat tails. Considering the range of behavioural responses to information will enable one to more effective communication with stakeholders about climate change risks and design decision aids and climate change policies designed to improve individual and social welfare and are likely to be implemented.

2.3 Models and Decision Aids for improving choices related to climate change

This section examines the role that more formal models and decision aids can play in assisting individuals, organization, communities and countries in making more informed choices with respect to climate change policies when faced with the risk and uncertainties characterized in Sect. 2.1.1. In this sense the tools discussed here can be used to facilitate System 2 behavior.

2.3.1 Expected utility theory

Expected utility [E(U)]theory (Ramsey, 1926; J. von Neumann and Morgenstern, 1944; Savage, 1954); remains the standard approach for providing normative guidelines against which other theories of decision-making under risk and uncertainty are benchmarked. According to the E(U) model the solution to a decision problem under uncertainty is reached by the following four steps:

I. Defining a set of possible decision alternatives

II. Quantifying uncertainties on possible states of the world

III. Valuing possible outcomes of the decision alternatives as utilities

IV. Choosing the alternative with the highest expected utility

This section clarifies the applicability of expected utility theory to the climate change problem, highlighting its potentials and limitations.

2.3.1.1 Elements of the theory

EU theory is based on a set of axioms that are claimed to have normative rather than empirical validity. Based on these axioms a person's subjective probability and utility functions can be determined by observing preferences in structured choice situations. These axioms have been debated, strengthened and relaxed for several generations: paradoxes have been generated and debated, empirical studies performed and alternatives elaborated. Nonetheless these axioms remain the basis for parsing decision problems in terms of probability and utility and seeking solutions that maximize expected utility.

2.3.1.2 How can expected utility improve decision making under uncertainty?

E(U) theory is a theory of individual choice: a farmer deciding what crops to plant or an entrepreneur deciding whether to invest in wind technology. Such individuals would apply E(U) theory by following the four steps above. The risk perception and behavior described in Sect. 2.2 that often characterize decision-making do not preclude making good (or lucky) choices. However, a structured approach such as the E(U) model can reduce the impact of probabilistic biases and simplified decision rules associated with intuitive processing, characterized in Section 2.2 as System 1 behavior. At the same time the limitations of E(U) must be clearly understood, as its complexity-reducing procedures and analytic processes do not capture the full range of information about outcomes and their risks and uncertainties.

Subjective versus objective probability

In the standard E(U) model, each individual has his/her own subjective probability measure over the set of possible worlds. Lay people are often inclined to defer to the views of experts, for questions relating to their field of expertise. When there is still considerable uncertainty surrounding the science experts' personal probabilities may diverge, sometimes substantially. In areas like climate change, observed relative frequencies are always preferred when suitable sets of observations are accessible. When observed relative frequencies are not available, uncertainty quantification must have recourse to structured expert judgment (see section 2.3.6).

Individual versus social choice

In applying E(U) theory to problems of *social choice* a number of issues arise. Condorcet's voting paradox shows that groups of rational individuals deciding by majority voting do not exhibit rational preferences. Decision conferencing under guidance of a skilled facilitator sometimes brings stakeholders to adopt a common utility function. AUTHORS TO REVIEWER: Reference required Unlike eliciting probabilities, however, there is no formal mechanism to induce agreement on utilities. Using a social utility or social welfare function to determine an optimal course of action for society requires some method of measuring society's preferences. Absent that, the social choice problem is not a simple problem of maximizing expected utility. A plurality of approaches involving different aggregations of individual utilities and probabilities may best aid decision makers. The basis and use of the social welfare function are discussed in section 3.2.2. .

Normative versus descriptive

As noted, the rationality axioms of EU are claimed to have normative as opposed to empirical validity. The paradoxes of Allais (1953) and Ellsberg (1961) reveal choice behaviour incompatible with E(U); whether this requires modifications of the normative theory is a subject of debate. McCrimmon (1968) found that business executives willingly corrected violations of the axioms, when made aware of them. Other authors (Kahneman and Tversky, 1979; Schmeidler, 1989; Quiggin, 1993; Wakker, 2010) account for such paradoxical choice behaviour by transforming the probabilities of outcomes into "decision weight probabilities" which play the role of likelihood in computing optimal choices but do not obey the laws of probability. Wakker (2010, p. 350) notes that decision weighting also fails to describe some empirically observed behaviour patterns. Whether decision makers *should* evaluate emission scenarios with 'decision weight probabilities' is a case that remains to be made.

2.3.2 Decision Analysis

2.3.2.1 Elements of the Theory

As defined by Ralph Keeney, decision analysis is "a formalization of common sense for decisions problems which are too complex for informal use of common sense" (Keeney, 1993). This definition highlights the role that a formal model can play in encouraging individuals to evaluate problems systematically in the spirit of System 2 behavior.

The foundations of decision analysis are provided by the axioms of expected utility theory. The methodology for choosing between alternative closely resembles that of utility theory and consists of the following elements that are described in more detail in Keeney (1993):

1. ***Structure the decision problem*** by generating alternatives and specifying values and objectives of the decision maker
2. ***Assess the possible impacts of different alternatives*** by determining the set of possible consequences and the probability of each occurring.
3. ***Determine preferences of relevant decision maker*** by developing an objective function that considers attitudes toward risk and aggregates the weighted objectives.
4. ***Evaluate and compare alternatives*** by computing the expected utility associated with each alternative. The alternative with the highest expected utility is the most preferred one.

To illustrate the application of decision analysis, consider a homeowner that is considering whether to invest in energy efficient technology as part of their choices involving *livelihood and lifestyle* as depicted in Table 2.1.

1. The person focuses on two alternatives: A1 Maintain the status quo and A2 Invest in Solar Panels, and has two objectives: O1 Minimize Cost and O2 Assist in Reducing Global Warming.
2. The homeowner would then determine the probabilistic impacts of A1 and A2 on the objectives O1 and O2
3. The homeowner would then consider its attitudes toward risks and then combine O1 and O2 into a multiattribute utility function.
4. The homeowner would then compare the expected utility of A1 and A2, choosing the one that had the highest expected utility

2.3.2.2 How Can Decision Analysis can Improve Decision-Making under Uncertainty?

Decision analysis enables one to undertake sensitivity analyses with respect to the uncertainties associated with the various consequences and to different value structures. Suppose alternative A1 had the highest expected utility. The homeowner could determine when the decision to invest in solar panels would be preferred to maintaining the status quo by asking questions such as the following:

- What would the annual savings in energy expenses have to be over the next 10 years to justify investing in solar panels?
- How many years would one have to reside in the house to justify investing in solar panels?
- What impact will different levels of global warming have on the expected costs of energy over the next 10 years for the homeowner to want to invest in solar panels?
- How will changing the relative weights placed on minimizing cost (O1) and assisting in reducing global warming (O2) affect the expected utility of A1 and A2?

2.3.3 Cost-benefit analysis and uncertainty

2.3.3.1 Elements of the theory

Cost Benefit Analysis (CBA) extends the concept of individual choice to the area of government decision-making by comparing costs and benefits of different alternatives. CBA is designed to select the alternative that has the highest social net present value based on a discount rate, normally constant over time, that converts future benefits and costs to their present values (Boardman et al., 2005). Social, rather than private, costs and benefits are compared including those affecting future generations (Brent, 2006). In this regard benefits across individuals are assumed to be additive. Distributional issues may be addressed by putting different weights on specific groups to reflect their relative importance. Under uncertainty one determines expected costs and benefits by weighting outcomes by their likelihood of occurrence. In this sense the analysis is similar to expected utility and decision analysis discussed in Sect. 2.1.2 and Sect. 2.1.3

CBA can be extremely useful when dealing with well-defined problems that involve a limited number of actors choosing among different local mitigation or adaptation measures. For example, a region could examine the benefits and costs over the next fifty years of building levees to reduce the likelihood and consequences of riverine flooding given projected sea level rise due to climate change.

CBA can also provide insights and a framework for defining safeguard a range of global targets on which to base negotiations across countries (see for example Stern & Britain, 2006). However, CBA faces major challenges when defining the optimal level of global mitigation actions, due to the need to determine and aggregate individual welfare, the presence of distributional and intertemporal issues and the difficulty of assigning probabilistic values to uncertain climate change impacts. Challenges of CBA in the context of climate change are discussed at length in Chapter 3. The discussion that follows focuses on challenges posed by risk and uncertainty.

2.3.3.2 How can CBA improve decision making under risk and uncertainty

Although cost-benefit analysis focuses on how specific policies impact on different stakeholders, it assumes that the decision-maker will eventually make a choice between well-specified alternatives. To illustrate this point, consider a region that is considering developing ways for coastal villages in hazard-prone areas to undertake measures for reducing future flood risks that are expected to increase, in part due to sea level rise. Several different options are being considered ranging from building a levee (at the community level) to providing low interest loans to encourage residents and businesses in the community to invest in adaptation measures to reduce future damage to their property (at the level of an individual or household).

Similar heuristics and resulting biases discussed in the context of expected utility theory apply to cost-benefit analysis under uncertainty. For example, the key decision maker, the mayor, may be subject to a threshold model by assuming that their region will not be subject to flooding because there have been no floods in the past 25 years. If they use unaided System 1 processes there would be no way to correct this behaviour until the next disaster occurred when the mayor would want to protect the community. The mayor and his advisors may also focus on short-time horizons, so that they do not want to incur the high upfront costs associated with building flood protection measures such as dams or levees because they consider only the expected benefits from the measures over the next several years rather than its lifetime.

CBA can help overcome behavior triggered by System 1 by highlighting the importance of considering the likelihood of events over time and the need to discounting exponentially so that the length of the time horizon matters. In addition CBA can highlight the tradeoffs between efficient resource allocation and distributional issues as a function of the weights assigned to different stakeholders (e.g. low income households in flood prone areas).

2.3.3.3 Advantages and limitations of CBA

The main advantage of CBA in the context of climate change is that it is internally coherent and based on the axioms of expected utility theory. As prices used to aggregate costs and benefits are the result of markets, CBA is in principle the best tool to represent people's preferences. Although the latter is one of the main arguments in favour of CBA (Tol, 2003), the same argument is often used against CBA by its opponents. Indeed, many impacts associated with climate change are not valued in any market and are therefore hard to measure in monetary terms. Omitting these impacts distorts the cost-benefit balance. There are tools available in environmental economics to value these impacts such as contingent valuation (Hanemann, 1994) or hedonic pricing methods (Rosen, 1974).

Several ethical and methodological critiques have been put forward with respect to the application of CBA to climate policy (Charlesworth and Okereke, 2010; Caney, 2011). The uncertainty surrounding the potential impacts of climate change, as well we the irreversible and catastrophic nature of some of the effects on the ecosystem and their very asymmetric distribution across the globe are at the foundation of the critiques to application of CBA in assessing the optimal response to climate change.

One strong and recurrent argument against CBA (Christian Azar and Lindgren, 2003; Tol, 2003; Weitzman, 2009, 2011; Nordhaus, 2011) is specifically related to its failure to deal with low probability, catastrophic events that might lead to unbounded measures of either costs and/or benefits. Under these circumstances, typically referred to as "fat tails" events, CBA is unable to produce meaningful results and more robust techniques are required. The debate concerning whether "fat tails" are indeed relevant to the problem at stake is still unsettled (see for example (Pindyck, 2011)).

One potential way to address this problem would be to focus on the potential catastrophic consequences of low-probability high-impact events when developing GHG emissions targets and leave off the extremes when the consequences from these outcomes do not demand serious consideration now. By specifying a threshold probability and a threshold loss one can remove extremes that are below these values in determining risk management strategies for dealing with climate change (H. Kunreuther, G. Heal, et al., 2013). Insurers and reinsurers utilize this approach in determining the amount of coverage that they are willing to offer against a particular risk. They diversify their portfolio of policies to keep the annual probability of a major loss below some threshold level (e.g. 1 in 1000) (H. Kunreuther, Pauly, et al., 2013)and (2013) is in the spirit of a classic paper by (Roy, 1952) on safety-first behavior. This procedure can be interpreted as an application of probabilistic cost effectiveness analysis (i.e. chance constrained programming) discussed in the next section. Itwas applied in a somewhat different manner to environmental policy by Ciriacy-Wantrup who contended that “a *safe minimum standard* is frequently a valid and relevant criterion for conservation policy.” (Ciriacy-Wantrup, 1971, p. 40).

2.3.4 Cost-effectiveness analysis and uncertainty

2.3.4.1 Elements of the theory

Cost-effectiveness analysis (CEA) is a tool based on constrained optimization for comparing policies designed to meet a prespecified target. The target can be defined through CBA, by applying a specific guideline such as the precautionary principle (see Sect. 2.3.5), or by specifying a minimum safety level or environmental standard. It could also be based on an ethical principle such as minimizing the worst outcome, in the spirit of a Rawlsian fair agreement, or as a result of the political and societal negotiation processes.

CEA does not evaluate benefits in monetary terms. Rather it is an attempt to find the least-cost option that achieves a desired quantifiable outcome. In ones sense CEA can be seen as a special case of CBA that replaces endogenous optimization of a climate policy based on costs and benefits with the objective of minimizing the cost of meeting an exogenous target (e.g. equilibrium temperature, radiative forcing, concentration or emission trajectory). CEA is often used by Integrated Assessment models (IAMs) to evaluate the costs of global/local climate policies (see Chapter 6 for more details on this).

Like CBA, CEA can be generalized to include uncertainty. One solution concept requires the externally set target to be specified with certainty and the objective of cost minimization replaced with by minimizing expected costs. A variation on this solution concept requires that the exogenous target such as an equilibrium temperature be exceeded with a pre-defined threshold probability.

This solution procedure, equivalent to chance constrained programming (CCP) (Charnes and WW Cooper, 1959) enables one to use stochastic programming, or other computational techniques to thus examine the impacts of uncertainty with respect to the cost of meeting a prespecified target.

2.3.4.2 How can CEA improve decision making under uncertainty?

To illustrate how CEA can be useful, consider a national government that wants to set a target for reducing greenhouse gas (GHG) emissions. It knows there is uncertainty as to whether specific policy measures will achieve the desired objectives. The uncertainties may be endogenous to the current negotiation process or related to proposed technological innovations. CEA could enable the government to assess mitigation strategies (or energy investment policies) for reducing GHG emissions in the face of these uncertainties.

2.3.4.3 Advantages and limitations of CEA over CBA

A crucial advantage of CEA over CBA in tackling the climate problem is that it does not require knowledge about climate damage functions currently being debated by experts but focuses on energy technology parameters where the knowledge by the scientific community is more advanced (NH Stern, 2007). A political decision process reflecting people's preferences, given their lack of knowledge of potential damage from different degrees of global warming, could determine the choice of a target. CEA narrows the range of uncertainties that need to be considered to those associated with mitigation costs. In several instances, as in the case of acid rain in Europe, CEA can move the decision process forward by overcoming the difficulties associated with estimating mitigation benefits that are required in a CBA analysis (Patt, 1999). CEA thus assists in overcoming biases related to assessing multiple and contrasting sources of uncertainty. The corresponding drawback is that the choice of the target is specified without considering its impact on economic efficiency. However, once costs to society are assessed and a range of targets is considered, one can assess people's preferences by considering the potential benefits and costs associated with different targets.

An important application of CEA in the context of climate change is evaluating alternative pathways that do not violate a pre-defined temperature target. A generalization of CEA to include uncertainty for this case is currently a topic of interest to researchers. Since temperature targets cannot be attained with certainty (M den Elzen and D van Vuuren, 2007; H. Held et al., 2009), formulating probabilistic targets is an appropriate solution technique to use. While CCP is a conceptually valid decision-analytic framework for examining the likelihood of attaining climate targets under probabilistic uncertainty without 'learning' (i.e. without changing the probability distributions that describe the decision-maker's state of knowledge in the course of time) (H. Held et al., 2009), introducing anticipated future learning can lead to self-conflicting prescriptions (Eisner et al., 1971). This phenomenon applies in particular to temperature targets (MGW Schmidt et al., 2010) so that the authors suggested develop an approach that combines CEA and CBA. The properties of this hybrid model (labelled *cost risk analysis*) require further investigation.

2.3.5 The precautionary principle and robust decision making

2.3.5.1 Elements of the theory

Any meaningful climate policy under conditions of uncertainty requires an adaptive decision-analytical framework that actively embraces the prospect of future learning. If a precise probability measure and the consequences of proposed actions for various states of the world were known to the decision maker, then the expected utility model could be used to determine a desirable adaptive policy. However, when the likelihood of specific events is highly uncertain—often referred to as 'Knightian uncertainty' (Lange and N. Treich, 2008)— non-probabilistic decision criteria need to be incorporated in the analysis. One criterion is *Minimax regret* where the alternative chosen is the one that minimizes the maximum possible regret for a perfectly informed decision-maker. The criterion of *Maximin* chooses the alternative that maximizes the minimum possible welfare while *Maximax* chooses the alternative that maximizes the maximum possible level of welfare. For each of these criteria one examines outcomes over all possible states of the world.

In the 1970s and 1980s, the precautionary principle (PP) was proposed for dealing with serious uncertain risks to the natural environment and to the public health (C. Vlek, 2010). In its strongest form the PP implies that if an action or policy has a suspected risk of causing harm to the public or to the environment, the burden of proof that it is *not* harmful falls on those taking the action. The PP allows policy makers to ban products or substances in situations where there is the possibility of their causing harm or extensive scientific knowledge on the matter is lacking. The principle implies that there is a social responsibility to protect the public from exposure to harm, when scientific investigation has found a plausible risk. These protections can be relaxed only if further scientific findings emerge that provide sound evidence that no harm will result. An influential statement of the PP with respect to climate change is principle 15 of the 1992 Rio Declaration on Environment and Development: "where there are threats of serious or irreversible damage, lack of full scientific certaintay shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

Robust decision making (RDM) is a particular set of methods and tools developed over the last decade to support decision-making and policy analysis under conditions of deep uncertainty and to address the PP in a systematic manner. RDM uses ranges or, more formally, sets of plausible probability distributions to describe deep uncertainty and to evaluate how well different policies perform over the range of these probability distributions. Lempert et al. (2006) and Hall et al. (2012) review the application of robust approaches to decisions with respect to mitigating or adapting to climate change. RDM can use an objective function that interpolates between a Minimax regret criterion and a maximize expected utility criterion. In these contexts, RDM provides decision makers with tradeoff curves that allow them to debate how much expected performance they are willing to sacrifice in order to improve outcomes in worst case scenarios. RDM thus captures the spirit of the precautionary principle in a way that illuminates the risks and benefits of different policies.

The 'tolerable windows approach' (TWA) (Bruckner and K. Zickfeld, 2008) can also be regarded a 'robust method'. Mathematically it is CEA or CCP without optimization. Targets are specified and the bundle of decision paths compatible with the targets is characterized. The selection of the relevant targets and the paths to achieving it are left to those making the decision.

Today's actions with respect to climate change will affect the risks borne by future generations (e.g. emissions today impacts on future environmental damage and future technology costs). This leads to what Gollier et al., (2000) have termed the *precautionary effect*. It can be shown that this effect is consistent with a reduction of current risk-exposure only under some specific and often restrictive conditions on the utility and damage functions (A Ulph and D Ulph, 1997). The 'precautionary effect' is defined within the EUmax framework and is discussed further in section 3.5.2. with respect to intertemporal choice.

2.3.5.2 How can RDM and the PP improve decision making under uncertainty?

RDM enables the decision maker to determine how well a set of alternative strategies including maintaining the status quo perform under different scenarios. To illustrate this point, consider a government agency that is developing a strategy for renewable energy to meet its country's greenhouse gas (GHG) reduction goals. RDM can examine a wide range of climate change scenarios based on estimates from the scientific community to see the impact of different renewable energy strategies on GHG emissions. The PP would require the government agency to examine worst case scenario and utilize a strategy that was optimal for this specific case. A Minimax approach could be used in this situation by choosing a policy that minimized the probability of a worst case scenario occurring.

2.3.6 Adaptive Management

Adaptive management is an approach to governance that explicitly incorporates mechanisms for reducing uncertainty over time that grew out of the field of conservation ecology in the 1970's (Holling and others, 1978; Walters and Hilborn, 1978). Two strands of adaptive management have been developed for improving decision-making uncertainty: *passive* and *active.*

Passive adaptive management (PAM) involves carefully designing monitoring systems, at the relevant spatial scales, so as to be able to track the performance of policy interventions and improve them over time in response to what has been learned. *Active adaptive management (AAM)* extends PAM by designing the interventions themselves as controlled experiments, so as to generate new knowledge. For example, if a number of political jurisdictions were seeking to implement support mechanisms for technology deployment, in an AAM approach they would deliberately design separate mechanisms somewhat differently across jurisdictions, recognizing that some mechanisms will underperform relative to others. By introducing such variance into the management regime, however, they would collectively learn more about how industry and investors respond to a range of interventions. All jurisdictions could then use this knowledge in a later round of policy-making.

Key stakeholders whose actions are triggered by processing information in System 1 mode hinder the kind of experimentation and risk taking that lead to new knowledge. More specifically, the status quo bias (Samuelson and Zeckhauser, 1988) and omission bias whereby individuals attach more personal blame to errors of commission rather than omission (Baron and Ritov, 1994) are impediments in this regard. In theory, adaptive management should correct this problem, by explicitly incorporating a learning dimension into policy-making. Illustrating this, Lee (1993) presented a paradigmatic case of AAM to increase salmon stocks in the Columbia River watershed in the western United States and Canada. Here, there was an opportunity to introduce a number of different management regimes on the individual river tributaries, and reduce uncertainty about salmon population dynamics by comparing their effects.

In practice, adaptive management can easily fall victim to the System 1 dynamics characterized above, and other institutional constraints and dynamics, such as the accountability elected officials in a state parliament feel towards the residents in their home district, rather than the citizens of the state as a whole. As Lee (1993) documented, policy-makers on the Columbia River were not able to carry through with AAM to the extent needed to restore fish stocks to viability; local constituencies, valuing their own interests over long-term learning in the entire region, played a crucial role in preventing this from occurring. it. One could imagine such issues as hindering even more the application of AAM at a global scale with respect to climate change policies.

To date there are no cases in the literature specifically documenting climate change policies in terms of AAM. However, there are a number of cases where policy interventions implicitly follow AAM principles. One of these is promotion of energy R&D. In this case the government invests in a large number of potential new technologies, with the expectation that some will not be pursued, while others will be successful and be supported by funding in the form of incentives such as subsidies. With respect to PAM, there are many documented cases of its applications in the area of climate change adaptation (Lawler and Et al.; Berkes et al., 2000; Berkes and Jolly, 2001; Joyce et al., 2009; Armitage, 2011). The information gathering and reporting requirements of the UNFCCC are in the spirit of PAM with respect to policy design as are the diversity of approaches implemented for renewable energy support across the states and provinces of North America and the countries in Europe. The combination of the variance in action with data gathered about the consequences of these actions by government agencies has allowed for robust analysis on the relative effectiveness of different instruments (Blok, 2006; Mendonça, 2007; L Butler and Neuhoff, 2008).

2.3.7 Uncertainty Analysis Techniques

Uncertainty analysis consists of both qualitative and quantitative methodologies. (See Box 2.2 for more details). A Qualitative Uncertainty Analysis (QLUA) helps improve the choice process of decision makers by providing data in a form that individuals can easily understand. QUA normally does not require complex calculations so that it can be useful in overcoming judgmental biases that characterize System 1 behavior. QLUA assembles arguments and evidence and provides a verbal assessment of plausibility, frequently placed in a Weight of Evidence narrative.

A quantitative uncertainty analysis (QNUA) assigns a joint distribution to uncertain parameters of a specific model used to characterize different phenomena. QNUA was pioneered in the nuclear sector in 1975 (Rasmussen, 1975) to determine the risks associated with nuclear power plants. Cooke (2012) reviews the development of QNUA and its prospects for application to climate change.

Box 2.2 Quantifying uncertainty

Natural language is not adequate for propagating and communicating uncertainty. To illustrate consider the US National Research Council 2010 report Advancing the Science of Climate Change (America's Climate Choices: Panel on Advancing the Science of Climate Change; National Research Council, 2010). Using the IPCC AR4 calibrated uncertainty language, the report bases its first summary conclusion on "high or very high confidence" in six statements (p.4,5). Paraphrasing the first two, the NRC is highly confident that (1) the Earth is warming and is also highly confident that (2) most of the recent warming is due to human activities.

What does the second statement mean? Does it mean they are highly confident that the Earth is warming AND the recent warming is anthropogenic or that given the Earth is warming, are they highly confident this warming is caused by humans? The latter seems most natural, as the warming is asserted in the first statement. In that case the "high confidence" applies to a conditional statement. The probability of both statements being true is the probability of the condition (Earth is warming) multiplied by the probability of this warming being human caused, given that warming is taking place. If both statements enjoy high confidence, then in the calibrated language of AR4 where high confidence implies a probability of .8, the statement that both are true would only be "more likely than not" (08×0.8=0.64).

Qualitative uncertainty analysis easily leads the unwary to erroneous conclusions. Interval analysis is a semi-qualitative method in which ranges are assigned to uncertain variables without distributions and can mask the complexities of propagation, as attested by an early hand book for risk analysis: *"The simplest quantitative measure of variability in a parameter or a measurable quantity is given by an assessed range of the values the parameter or quantity can take. This measure may be adequate for certain purposes (e.g., as input to a sensitivity analysis), but in general it is not a complete representation of the analyst's knowledge or state of confidence and generally will lead to an unrealistic range of results if such measures are propagated through an analysis"* (U.S. NRC, 1983). These same concepts are widely represented throughout the uncertainty analysis literature. According to Morgan and Henrion (1990): "*Uncertainty analysis is the computation of the total uncertainty induced in the output by quantified uncertainty in the inputs and models…. Failure to engage in systematic sensitivity and uncertainty analysis leaves both analysts and users unable to judge the adequacy of the analysis and the conclusions reached*(Morgan and Henrion, 1990, p. 39).

2.3.7.1 Structured expert judgment

Structured expert judgment designates methods in which experts quantify their uncertainties to build probabilistic input for complex decision problems (Morgan and Henrion, 1990; Cooke, 1991; O'Hagan, 2006). A wide variety of activities falls under the heading *expert judgment* that include blue ribbon panels, Delphi surveys and decision conferencing.

Elements

Structured expert judgment as science-based uncertainty quantification was pioneered in the Rasmussen Report on risks of nuclear power plants (Rasmussen, 1975), and the methodology was further elaborated in successive studies. The most recent benchmark involves treating experts as statistical hypotheses whose performance is evaluated is based on assessments of variables from their field whose true values are known post hoc. Protocols for expert selection and training, elicitation procedures and performance-based combinations are also formulated (see special issue Radiation Protection Dosimetry LHJ Goossens et al., 2000). Should expert performance not be validated, then the experts' distributions are combined with equal weighting or not combined. In large studies, multiple expert panels provide inputs to large computer models, and there is no practical alternative to combining expert judgments except to use equal weighting. Hora (2004) showed that equal weight combinations of statistically accurate ("well calibrated") experts, loses statistical accuracy. Performance based combinations have performed well in practice (Cooke and LLHJ Goossens, 2008; WP Aspinall, 2010).

How can this tool improve decision making under uncertainty?

Structured expert judgment can provide insights into the nature of the uncertainties associated with a specific risk and the importance of undertaking more detailed analyses to design meaningful strategies and policies for dealing with climate change in the spirit of System 2 behavior. in addition to climate change (Morgan and D. W Keith, 1995; Kirsten Zickfeld et al., 2010), structured expert judgment has migrated into many fields such as volcanology (WP Aspinall, 1996, 2010), dam dyke/safety (WP Aspinall, 2010), seismicity (Klügel, 2008), civil aviation (Ale et al., 2009), ecology (Martin et al., 2012; Rothlisberger et al., 2012), toxicology (Tyshenko et al., 2011), security (JJCH Ryan et al., 2012) and epidemiology (Tuomisto et al., 2008).

General conclusions from the experience to date are: (1) formalizing the expert judgment process and adhering to a strict protocol adds substantial value to understanding the importance of characterizing uncertainty, (2) experts differ greatly in their ability to give statistically accurate and informative uncertainty quantifications, and (3) if expert judgments must be combined to support complex decision problems, the method of combination should be subjected to the same quality controls as the experts themselves (WP Aspinall, 2010).

As attested by a number of governmental guidelines and high visibility applications, structured expert judgment is increasingly accepted as "quality science" that is applicable when other methods are unavailable (U.S. Environmental Protection Agency, 2005). Climate science has also seen some application of structured expert judgment and some less formal applications (Nordhaus, 1994; Weitzman, 2001). Structured expert judgments of climate scientists was recently used to quantify uncertainty in the ice sheet contribution to sea level rise.

To illustrate the use of structured expert judgment in the context of climate change, damages or benefits to ecosystems from invasions of non-indigenous species are impossible to quantify and monetize on the basis historical data. However ecologists, biologists and conservation economists have substantial knowledge regarding the possible impacts of invasive species. Recent studies (Rothlisberger et al., 2009, 2012) applied structured expert judgment with a performance-based combination and validation to quantify the costs and benefits of the invasive species introduced since 1959 into the U.S. Great Lakes by opening the St. Lawrence seaway. Nine experts assessed 12 calibration variables relating to near future fishing effort and catches. Combining the experts' assessments with equal weight yielded poor statistical behaviour, but the combination based on performance yielded satisfactory statistical results. Lessons from such studies are (1) the existence of large uncertainties need not paralyse quantitative analysis, (2) experts may have applicable knowledge that can be captured in a structured elicitation and (3) statistical validation of experts and combinations of experts is possible.

Advantages and limitations of structured expert judgment

Expert judgment studies do not reduce uncertainty; they merely quantify it. If the uncertainties are large, as indeed they often are, then decision makers hoping that science will relieve them of the burden of deciding under uncertainty may be disappointed. Since its inception, structured expert judgment has met scepticism in some quarters, as it is, after all, just opinions and not hard facts. Its steady growth and widening acceptance over 35 years correlates with the growth of complex decision support models which outstrip conventional data resources. Structured expert judgment provides some measure of validated quantitative input in these contexts, but it must never justify a diminution of effort for collecting hard data.

2.3.7.2 Scenario analysis and ensembles

Scenario analysis develops a set of possible futures based on extrapolating current trends and varying key parameters, without sampling in a systematic manner from an uncertainty distribution. Sufficiently long time horizons ensure that structural changes in the system are considered. The futurist Herman Kahn and colleagues at the RAND Corporation are usually credited with inventing scenario analysis (H Kahn and Wiener, 1967). In the climate change arena, scenarios are currently presented as different emission pathways or Representative Concentration Pathways (RCPs). Predicting the effects of such pathways involves modelling the earth's response to the forcing from anthropogenic greenhouse gases, in combination with other known forcings and policy responses. Different climate models will yield different projections for the same emission scenario. Model inter-comparison studies generate sets of projections termed ensembles.

Elements of the theory

In Kahn's classical scenario analysis, current trends are identified and extrapolated into the future to determine a "surprise free scenario". Canonical variations are then projected by changing parameters in the surprise free scenario. Unknown parameters are often given extreme values, usually one at a time, with the intention of circumscribing the space of possibilities. Systematic ways of choosing parameter values to cover the space of possibilities efficiently are based on design of experiments.

This picture has evolved substantially within the climate modeling community. Currently, RCPs are carefully constructed on the bases of plausible storylines while insuring (1) they are based on a "representative set" of peer reviewed scientific publications by independent groups, (2) they provide input climate and atmospheric models, (3) they are harmonized to agree on a common base year, and (4) they extend to the year 2100. The four RCP scenarios shown in Figure 2.2 span the radiative forcing values in the literature. The grey areas representing the 98th percentiles are based on a large set of scenarios.

Note that a "representative set" is not a "random sample" from the scenarios in the literature. Indeed, there are many more scenarios in the middle of the distribution than at the extremes. The set of scenarios in the literature may of course be considered as an empirical distribution in its own right, but it does not represent independent samples from some underlying uncertainty distribution over unknown parameters. The scenarios underlying the RCPs were originally developed by four independent integrated assessment models, each with their own carbon cycle. To provide the climate community with four harmonised scenarios they were run through the same carbon cycle/climate model (Meinshausen et al., 2011).

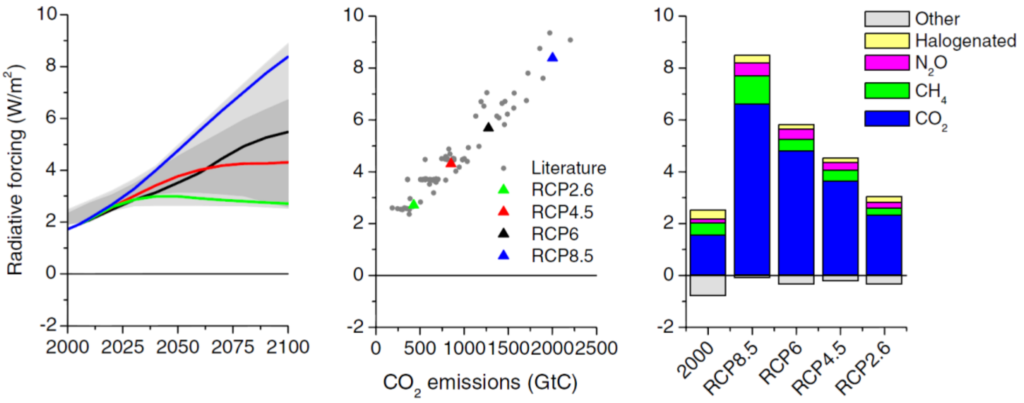


Figure 2.2. Trends in radiative forcing (left), cumulative 21st centuryCO2 emissions vs 2100 radiative forcing (middle) and 2100 forcing level per category (right). Grey area indicates the 98th and 90th percentiles (light/dark grey) of the literature. The dots in the middle graph also represent a large number of studies. Forcing is relative to pre-industrial values and does not include land use (albedo), dust, or nitrate aerosol forcing (D. P. van Vuuren et al., 2011).

Ensembles of model runs generated by different models, called multimodel ensembles or super–ensembles, are used to estimate the natural climate variability. An optimal signal for detecting climate change takes the natural variability of the signal's components into account. Since the historical record is too short to assess this variability, long term multimodel ensembles are used (Zwiers, 1999). Multimodel ensembles are also used to convey the scatter around reference scenarios. Figure 2.3 shows an example from the World Climate Research Programme, Coupled Model Intercomparison Project (CMIP5) that requires a set of historical and future pathways for both concentrations and emissions (see Appendix 1), ideally produced by a single model.

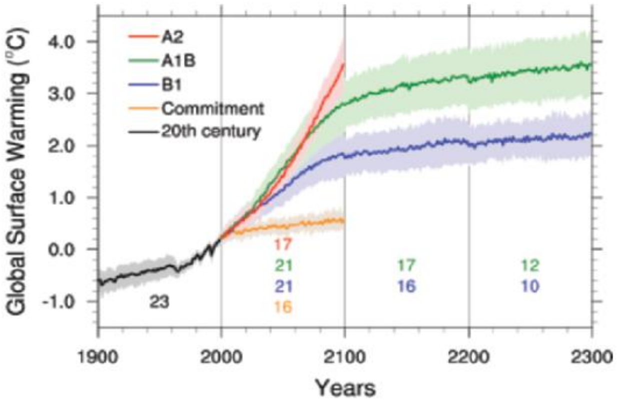


Figure 2.3. Multimodel means of surface warming for the twenty-first century for the scenarios A2, A1B and B1, and corresponding twentieth-century simulations. Values beyond 2100 are for the climate change commitment experiments that stabilized concentrations at year 2100 values for B1 and A1B. Linear trends from the corresponding control runs have been removed from these time series. Lines show the multimodel means, and shading denotes the ±1 std dev intermodel range. Discontinuities between different periods have no physical meaning due to the fact that the number of models run for a given scenario is different for each period and scenario, as indicated by the numbers given for each phase and scenario in the bottom part of the panel (Meehl et al., 2007)

The shaded areas in Figure 2.3 denoting "the ± 1 stdev intermodal range" can easily lead the unwary reader to believe that the true values are 68% certain to fall in the shaded areas. This would be true if the model runs were independent samples of a normal distribution with the stated standard deviations with expectations equal to the true values. Note that there are only 10 samples estimating the mean and standard deviation in scenario B1 between 2200 and 2300.

Moreover, as pointed out in Hansen et al. (2011) many of these models have common ancestors, creating dependences between different model runs. Objective probability statements on global surface warming require estimating the models' bias and interdependence.

Advantages and limitation of scenario and ensemble analyses

Scenario/ensemble analyses are an essential step in scoping the range of effects of human actions and climate change. The advantage of scenario / ensemble analyses is that they can be performed without quantifying the uncertainty of the underlying unknown parameters. On the downside, it is easy to read more into these analyses than is justified. Analysts often forget that scenarios are illustrative possible futures along a continuum. They tend to use one of those scenarios in a deterministic fashion without recognizing that they have a low probability of occurrence and are only one of many possible outcomes. The use of probabilistic language in describing the swaths of scenarios may also encourage the misunderstandings that these represent science-based ranges of confidence.

Box 2.3. Reducing uncertainties of climate change impacts through higher resolution

To assess impacts of climate change, countries must be able to construct future climate scenarios and their relative likelihood. Such scenarios currently exist at the global level through Global Change Models (GCM) providing resolution of a few hundred kilometers but are not very useful for small islands such as those in the Caribbean.

Fortunately, methodologies exists that can produce high resolution from the coarser GCM outputs. These are commonly referred as *regionalization* or *downscaling.* One of these techniques is regional climate modeling, an attractive option for the region because simulations are possible where the terrain is not flat. It enables one to predict climate change with more detail for smaller islands as well as characterizing the risk of extreme events such as hurricanes and to be used to drive other models. PRECIS (providing regional climates for impact studies) is one such regional modeling system developed at the Hadley Centre, UK and is currently being used in the Caribbean with information corresponding to a range of SRES emission scenarios. PRECIS has a horizontal resolution of 0.44^0 (~50 km) or 0.22^0 (~ 25 km) and 19 levels in the vertical (MA Taylor et al., 2007).

2.4 Risk and uncertainty in climate change policy issues

2.4.1 Guidelines for developing policies

The Introduction (Sect. 2.1) characterized how risks and uncertainties associated with physical, biological, and social systems are relevant for decision-making and designing climate policy. Section 2.2 explained how people typically respond to these risks and uncertainties and Section 2.3 detailed how formal models and decision aids can help the relevant interested parties make more informed choices under conditions of risk and uncertainty. This section assesses how the risks and uncertainties associated with climate change can and should affect actual policy choices.

At the time of the AR4, there was some modeling-based literature how uncertainties affected policy design, but very few empirical studies. In the intervening years, international negotiations failed to establish clear national emissions reductions targets, but have established a set of normative principles, such as the 2°C global warming target. These are now reflected in international, national, and subnational planning processes and have affected the risks and uncertainties that matter for new climate policy development. Greater attention and effort has been given to find synergies between climate policy and other policy objectives, so that it is now important to consider multiple benefits of a single policy instrument. For example, efforts to protect tropical rainforests (McDermott et al., 2011), rural livelihoods (Lawlor et al., 2010), biodiversity (Jinnah, 2011), public health (Stevenson, 2010), fisheries (Axelrod, 2011), arable land (Conliffe, 2011), energy security

(Battaglini et al., 2009), and job creation (Barry et al., 2008) have been framed as issues that should be considered when evaluating climate policies.

Table 2.1, in the Introduction to this chapter, highlights many of the uncertainties that play an important role when making choices between climate policies. This section reviews the literature providing support for the taxonomy that forms the basis for Table 2.1. More specifically:

- Section 2.4.2 presents the results of integrated assessment models that address the choice of a climate change target or the optimal transition pathway to achieve a particular target. These studies typically focus on a social planner operating at the international level. While there is an extensive literature highlighting the importance of uncertainties in climate sensitivity and climate damage costs mediated by ecosystem considerations, more recent studies have shown that other uncertainties may be at least as important in determining the costs of climate change and the choice of policies and instruments.

- Section 2.4.3 summarizes the findings from modeling and empirical studies that examine the processes and architecture of international treaties. These again show sensitivity to technological uncertainties, whereby individual countries may find it difficult to estimate their future abatement costs that will influence their level of commitment. In the area of compliance enforcement, the studies also show sensitivity to uncertainties in the carbon cycle, which make it difficult to pinpoint countries' actual emissions, particularly with respect to changes in land use.

- Section 2.4.4 presents the results of modeling studies and the few empirical analyses that examine the choice of particular policy instruments at the sovereign state and subnational decision making loci. The studies show this choice to be sensitive to uncertainties in how different technologies will perform, now and over time. These different instruments inject different sets of incentives into the market so their effectiveness and efficiency depend on how firms and consumers respond to them. A growing number of papers show that their responses are influenced by regulatory risk and/or market uncertainty.

- Section 2.4.5 discusses empirical studies of people's support or opposition with respect to changes in investment patterns and livelihood or lifestyles that climate policies will bring about. On the one hand, these studies show that people's support for a specific policy is often contingent on how they perceive that climate change will affect their personal health or safety risks. On the other hand, they show that support for particular low carbon development pathways are also contingent on the health and safety risks associated with the new technologies themselves.

FAQ 2.3. When is uncertainty a reason to wait and learn rather than acting now in relation to climate policy and risk management strategies?

Across a wide range of policy situations, uncertainty is sometimes a reason to wait and learn before taking a particular action, and sometimes a reason to take the action and learn later. Generally, waiting and learning is likely to be desirable when external events generate new information of sufficient importance as to suggest the planned action would be unwise. Uncertainty is not likely to be a reason to delay action when external events are highly unlikely to generate new information of sufficient importance during the relevant time frame for which the action is considered, or when it is the action itself that generates the new information and knowledge.

While these criteria themselves are fairly easy to understand, their application to actual decision problems can be complicated because there may be a number of uncertainties that are relevant for a given decision. For example, deciding whether or not to engage in aggressive mitigation at a global level is contingent on estimates of the costs of both climate damages and technological change, both of which are uncertain. Different interested parties may reach different conclusions as to whether external information is likely to be of sufficient importance as to render the original action regrettable due to their perception as to what data will be generated and its value with respect to possible outcomes.

A large number of studies examine the question as to whether to act now or wait and see in the context of policy choices at the global level such as how much and how quickly to mitigate, at the national level concerning policy strategies and instruments to achieve mitigation targets, and at the firm or individual level as to whether one should invest in a particular technology. Most of these analyses have focused on global mitigation targets using integrated assessment models (IAMs).
What has not yet occurred is a truly integrated analysis of the effects of multiple types on uncertainty on multiple interrelated policy decisions, such as how much to mitigate, with what policy instruments, promoting what investments. The probabilistic information needed to support such an analysis, is currently not available.

2.4.2 Optimal or efficient stabilization pathways (social planner perspective) under uncertainty

Integrated assessment models (IAM) are tools capable of representing the interplay of economic activities, other human activities and the dynamics of the natural system in response to various choices open to society. In IAMs a representative agent (social planner), who is modelled as a System 2 decision maker undertaking complex computations, maximizes intertemporal aggregate welfare or minimizes total costs to society to reach a prespecified target. Chapter 6 describes in details the structures and calibration procedures of IAMs. Here we focus on IAM results where uncertainty is an integrated part of the decision-analytic framework. We also examine the effect of variations in uncertain parameters' values through Monte-Carlo analyses.

Climate policy assessment should be considered in the light of uncertainties associated with climate or damage response functions, the costs of mitigation technology and the uncertainty in climate change policy instruments. The key question these analyses address is how uncertainty alters the optimal social planner's short term reaction to climate change. A subset also asks whether adjusting behaviour to uncertainty and designing more flexible policies and technology solutions would induce a significant welfare gain.

Table 2.2 provides an overview of the existing literature on IAMs that examine mitigation actions. The three columns categorizes the literature on the basis of whether including uncertainty in the analysis accelerates, delays or has an ambiguous effect on short-term mitigation activity. The rows classifies the literature on the basis of what type of uncertainty is considered. In particular we group uncertainty sources on upstream (related to emission baseline drivers), downstream continuous (related to climate feedback and damage), downstream catastrophic (related to threshold climate feedbacks and damages), policy responses (related to the uncertain adoption of policy tools), and multiple sources (when more than one of the sources above are considered simultaneously). There appears to be consensus in the literature that the inclusion of uncertainty implies a more significant short-term mitigation response to climate change. An important exception arises only when continuous climate-feedback damages uncertainty is considered (second row of Table 2.2) in which case an ambiguous or negative impact on early mitigation action predominates. Although studies differ in their approaches, the main underlying reason for not undertaking short-term mitigation measures action is when the irreversible sunk cost investment in abatement options outweighs the irreversible effect of climate change. This is particularly relevant in studies where catastrophic/threshold damage is not included in the picture and no consideration is given to the non-climate related benefits of these investments such as enhancing energy security.

Although IAMs mimic System 2 decision makers, in reality social planners might resort to System 1 processes to simplify their decision processes, leading to biases and inferior choices. To date there is no research that considers such behaviour by decision makers and examines how it relates to the optimal projections of IAMs. We discuss the need for such studies in the concluding section on Future Research.

Table 2.2. Overview of literature on integrated assessment models examining mitigation actions

		Effect on Mitigation Action					
		Accelerates / Increases Mitigation Action		***Delays / Decreases Mitigation Action***		***Ambiguous Effect***	
		References (left: number of papers)		References (left: number of papers)		References (left: number of papers)	
Type of Uncertainty Considered	***Up Stream (emission drivers)***	6	Kelly and Kolstad (2001), Cooke (2012), (JM Reilly et al., 1987; Webster et al., 2002; O'Neill and Sanderson, 2008; Rozenberg et al., 2010)	0		0	
	Down Stream (climate and damages) - Continuous	3	(Chichilnisky and Geoffrey Heal, 1993; Peck and Teisberg, 1994; Syri et al., 2008; Athanassoglou and Xepapadeas, 2011)	3	(Charles D. Kolstad, 1994; C. D Kolstad, 1996; Baranzini et al., 2003)	10	(HR Clarke and WJ Reed, 1994; C. D. Kolstad, 1996; Tsur and Zemel, 1996; Christian Gollier et al., 2000; AC Fisher and Narain, 2003; Minh Ha-Duong and Nicolas Treich, 2004; Erin Baker et al., 2006; Lange and N. Treich, 2008; Lorenz et al., 2012; A Ulph and D Ulph, 2012)

	Down Stream (climate and damages) - Catastrophic event	15	(M. Ha-Duong, 1998; Gjerde et al., 1999; BC O'Neill and Oppenheimer, 2002; Baranzini et al., 2003; Dumas and Minh Ha-Duong, 2005; Hope, 2008; Webster, 2008; Tsur and Zemel, 2009; Funke and Paetz, 2011a; Lorenz et al., 2012; de Zeeuw and Zemel, 2012) Lorenz et al. (2012b), Gollier and Treich (2003), McInerney & Keller (2008),Heal (1984), Inverson and Perrings (2012).	1	(Peck and Teisberg, 1995)	0	
	Policy Response	6	(Minh Ha-Duong et al., 1997; Blanford, 2009; V. Bosetti and M. Tavoni, 2009; Valentina Bosetti et al., 2009; Durand-Lasserve et al., 2010) Farzin & Kort (2000),	2	(Baudry, 2000; Erin Baker and Ekundayo Shittu, 2006)	0	
	Multiple sources of Uncertainy	14	(Nordhaus and Popp, 1997; M Grubb, 1997; Pizer, 1999; Tol, 1999; M. Obersteiner et al., 2001; Yohe et al., 2004; Klaus Keller et al., 2004; E. Baker and E. Shittu, 2008; Erin Baker and Adu-Bonnah, 2008; Bahn et al., 2008; H. Held et al., 2009; HOPE, 2009; Labriet et al., 2010) Nordhaus (1994)	1	(MJ Scott et al., 1999)	1	(Manne and Richels, 1991)

2.4.2.1 Analyses predominantly addressing climate or damage response uncertainty

The explicit inclusion of climate or damage response uncertainty in decision-making may lead to shifts in policy recommendations even on short-term behaviour. The literature (as assembled in Table 2.2) shows that this effect of uncertainty crucially depends on two conditions: whether the recommendations are derived from a target-based approach using cost-effectiveness analysis (CEA) or from weighing mitigation costs and benefits using cost-benefit analysis (CBA). When CBA is utilized one also needs to consider whether thresholds, strong nonlinearities, irreversibilities or fat-tail-like behaviour characterize the link from emissions to impacts.

When undertaking a CBA under the assumption of only mildly nonlinear climate change damages in response to temperature rise (see Table 2.2, 'Downstream - continuous'), the effect of uncertainty is ambiguous (e.g., Athanassoglou and Xepapadeas, 2011).[2] For thresholds, strong nonlinearities, irreversibilities or fat-tail-like behaviour (see Table 2.2, 'Downstream – catastrophic events') on the damage side, including uncertainty in a CBA leads to an enhanced mitigation effort, although the effect is likely to be minor if climate change damages occur far in the future (D McInerney and Klaus Keller, 2007). The same effect appears if one assumes that a temperature target will be met with a

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[2] The reason is that uncertainty in combination with convex damages suggests an enhanced mitigation effort. However (Hof et al., 2010; Lorenz et al., 2012) show that this effect is often compensated by other nonlinearities such as a concave concentration-temperature relation. The effects of uncertainty also depend on whether uncertainty is expected to be reduced (Kelly and Kolstad, 1999).

probability greater than 2/3. In this climate or damage response uncertainty suggests decade-scale earlier investments in mitigation technologies ten years earlier than if these responses were certain (H. Held et al., 2009). Learning about uncertain properties in the future can reduce the impact of this uncertainty on the timing of mitigation investments (Webster et al., 2008).
The above literature characterizes uncertainty through the probability of climate change and/or damage responses occurring. Climate scientists feel that these likelihoods can be precisely specified precisely. When these probabilities are uncertain the investment in mitigation will be enhanced (see e.g., Hof et al., 2010; Funke and Paetz, 2011b).

2.4.2.2 Analyses predominantly addressing policy responses uncertainty

In this area there are two strands of research. The first has focused on examining how the extent and timing of mitigation investments are affected by the uncertainty on the effectiveness of Research, Development and Demonstration (RD&D) and/or the future cost of technologies for reducing the impact of climate change. An example of this would be, the optimal investment in energy technologies that a social planner should undertake knowing that there might be a nuclear power ban in the near future. Another strand of research looks at the uncertainty concerning future climate policy instruments as well as their stringency in combination with climate and/or damage uncertainty affects a mitigation strategy. An example would be the optimal technological mix in the power sector to hedge future climate regulatory uncertainty.

With respect to the first strand, the main challenge is to quantify uncertainty related to the future costs of mitigation technologies. Indeed, there does not appear to be a single stochastic process that underlies all (RD&D) programs or the process of innovation. Thus elicitation of expert judgment on the probabilistic improvements in technology performance and cost becomes a crucial input for numerical analysis. A literature is emerging (Curtright et al., 2008; see for example E. Baker et al., 2008; GL Chan et al., 2010; E. Baker and Keisler, 2011), that uses expert elicitation to investigate the uncertain effects of RD&D investments on the prospect of success of mitigation technologies. In future years, this will allow the emergence of a literature studying the probabilistic relationship between R&D and the future cost of energy technologies in IAMs. The few existing papers reported in Table 2.2 under the Policy Response uncertainty column (see Blanford, 2009; V. Bosetti and M. Tavoni, 2009) point to increased investments in energy RD&D and in early deployment of carbon free energy technologies in response to uncertainty.

Turning to the second strand of literature reported in the Policy Response or in the Multiple Uncertainty columns of Table 2.2 (see M. Ha-Duong et al., 1997; E Baker and E Shittu, 2006; Durand-Lasserve et al., 2010), most analyses imply increased mitigation in the short term when there is uncertainty about future policy stringency due to the asymmetry of future states of nature: the “no policy” case implies losses of carbon free capital; these would be more than outweighed by the potential losses of delayed mitigation and the extremely fast decarbonisation that would be required if a “stringent climate policy” state of nature were realized.

2.4.3 International negotiations and agreements under uncertainty

Social planner studies, as reviewed in the previous sub-sections, consider the appropriate magnitude and pace of aggregate global emissions reduction. These issues have been the subject of negotiations at the international level along with the structuring of national commitments and the design of mechanisms for compliance, monitoring and enforcement.

2.4.3.1 Treaty formation

There exists a vast literature looking at international treaties in general and how these might be affected by uncertainties. Cooper (1989) has examined two centuries of international treaties to control the spread of communicable diseases and concludes that it is only when uncertainty is largely resolved that countries will enter into international treaties. Young (1994), on the other hand, suggests that it may be easier to enter into treaties when parties are uncertain as to their

individual net benefits from an agreement than when that uncertainty has been resolved. Coalition theory predicts that international negotiations related to a global externality such as climate change, stable coalitions will be generally small and/or ineffective (Barrett, 1994). Recently, DeCanio and Fremstad (2011) show how the recognition of the seriousness of a climate catastrophe on the part of leading governments could transform a prisoner's dilemma game into a coordination game leading to an increased likelihood of reaching an international agreement to limit emissions.
Relatively little research has been undertaken on how uncertainty affects the stability of multilateral environmental agreements (MEAs) and when uncertainty and learning has the potential to unravel agreements. Kolstad (2007), using a game theoretic model, looks specifically at environmental agreements and investigates the extent to which the size of the largest stable coalition changes as a result of learning and systematic uncertainty. He finds that systematic uncertainty by itself decreases the size of an MEA. Kolstad and Ulph (2008) show that partial or complete learning has a negative impact on the formation of an MEA since it reduces the welfare benefits to some countries from joining a coalition and hence reduces the number of countries who are viable candidates for the MEA. Baker (2005), using a model of the impacts of uncertainty and learning in a non-cooperative game, shows that the level of correlation of damages across countries is a crucial determinant of outcome.

Barrett (2011) has investigated the role of catastrophic, low probability events on the likelihood of cooperation with respect to a global climate agreement. By comparing a cooperative agreement with the Nash equilibrium it is possible to assess a country's incentives for participating in such an i agreement. As noted by Heal and Kunreuther (2011), the signing of the Montreal Protocol by the United States led many other countries to follow suit. They utilize the lessons from the Montreal Protocol to suggest how it could be applied to foster an international treaty on greenhouse gas emissions by tipping a non-cooperative game from an inefficient to an efficient equilibrium.

Several analyses, including Victor (2011) and Hafner-Burton et al. (2012), contend that the likelihood of a successful comprehensive international agreement for climate change is low because of the sensitivity of negotiations to uncertain factors, such as the precise alignment and actions of participants. Keohane and Victor (2011), in turn, suggest that the chances of a positive outcome would be higher in the case of numerous, more limited agreements. LDCs have been unlikely to adopt international agreements due in part to negotiations being dominated by the interests of developed countries. They will have to enhance their negotiating power in international climate change discussions by highlighting their concerns for the situation to change (Rayner and Malone, 2001).

2.4.3.2 Strength and form of national commitments

Buys et al. (2009) construct a model to predict national level support for a strong global treaty based on the risks that parties to the treaty face domestically. They distinguish between vulnerabilities to climate impacts and climate policy restrictions with respect to carbon emissions. Buys et al suggest that countries would be most supportive of strong national commitments when they are highly vulnerable to climate impacts and their emitting sectors are not greatly affected by stringent policy measures and least supportive of making these commitments when the reverse is true. They do not, however, test their model empirically.

Victor (2011) analyzes the structure of the commitments themselves, or what Hafner-Burton et al. (2012) call rational design choices. Victor suggests that while policy makers have considerable control over the carbon intensity of their economies, they have much less control over the underlying economic growth of their country. As a result, there is greater uncertainty on the magnitude of emissions reductions, which depends on both factors, than on the reductions in carbon intensity. Victor suggests that this could account for a reluctance of many countries to make strong binding commitments with respect to emissions reductions. Consistent with this reasoning, Thompson (2010) examined negotiations within the UNFCCC at two points in time, and found that uncertainty with respect to national emissions was not associated with increased support for a national commitment to a global treaty.

Webster et al. (2010) examined whether uncertainty with respect to national emissions increases the potential for individual countries to hedge by joining an international trade agreement. They found that hedging had a minor impact compared to the other effects of international trade, namely burden sharing and wealth transfer. These findings may have relevance for structuring a carbon market to reduce emissions by taking advantage of disparities in marginal abatement costs across different countries. In theory, the right to trade emission permits or credits could lessen the uncertainties associated with any given country's compliance costs compared to the case where no trading were possible. Under a trading scheme if a country discovered its own compliance costs to be exceptionally high, for example, it could purchase credits on the market.

2.4.3.3 Design of monitoring, verification regimes and treaty compliance

A particular important issue in climate treaty formation and compliance is uncertainty with respect to actual emissions from industry and land use. Monitoring, reporting, and verification (MRV) regimes have the potential to set incentives for participation in a treaty and still be stringent, robust and credible with respect to compliance. Problems are created because estimating emissions, especially in the land use sector in many developing countries, is so uncertain that the effects of changes in managing carbon emissions could be undetectable given error bounds associated with measuring emissions. Researchers have suggested that the carbon source that is most problematic from the MRV perspective is soil carbon (Bucki et al., 2012).

In the near term, requiring an MRV regime of the highest standards and accuracy could require data that currently is available only in wealthy countries, thus precluding the least developed countries (LDCs) from participating (Oliveira et al., 2007). By contrast, there are design options for MRV regimes that are less accurate, but which still address the drivers of emissions so that the LDCs could be part of the system. By being more inclusive these options could be a more effective way to actually reduce emissions in the near term (Bucki et al., 2012).

In the longer term, robust and harmonised estimation of emissions and their removal in agriculture and forestry requires investment in monitoring and reporting capacity, especially in developing countries (Böttcher et al., 2009; Romijn et al., 2012). Reflecting this need for an evolving MRV regime to match data availability, the 2006 Guidelines for National Greenhouse Gas Inventories, prepared by an IPCC working group, suggested three hierarchical tiers of data for emission and carbon stock change factors with increasing levels of data requirements and analytical complexity. These range from tier 1 (using IPCC default values of high uncertainty) to tier 2 (using country-specific data) and tier 3 (using higher spatial resolution, models, inventories). In 2008, only Mexico, India and Brazil had the capacity to use tier 2 and no developing country was able to use tier 3 (Hardcastle and Baird, 2008). Romijn et al.,(2012) found more recently that only four tropical countries had a very small capacity gap regarding the monitoring of their forests through inventories while the remaining 48 countries had none to limited ability to undertake this monitoring process.

In order to overcome the gaps and uncertainties associated with lower tier approaches, different principles can be applied to form pools (Böttcher et al., 2008). For example, a higher level of aggregation by including soil and litter, harvested products in addition to a biomass pool as part of the MRV regime decreases relative uncertainty: the losses in one pool (e.g. biomass) are likely to be offset by gains in other pools (e.g. harvested products) (Böttcher et al., 2008). The exclusion of a pool (e.g. soil) in an MRV regime should be allowed only if adequate documentation is provided that this produces a conservative estimate of emissions (i.e. the estimate is likely to be at least as high as the unknown actual values) (Grassi et al., 2008). An international framework also needs to create incentives for investments. In this respect, overcoming initialization costs and unequal access to monitoring technologies is crucial for implementation of an integrated monitoring system, and fostering international cooperation (Böttcher et al., 2009).

2.4.4 Choice and design of policy instruments under uncertainty

Whether motivated primarily by a binding multilateral climate treaty or by some other set of factors, there is a growing set of policy instruments that countries have implemented or are considering for dealing with climate change. Some policy instruments operate by mandating particular kinds of behaviour, such as the installation of pollution control technology, or limits on emissions from particular sources. There is an extensive literature in political science demonstrating that the effects of these instruments are fairly predictable (Shapiro and McGarity, 1991) and are insensitive to market or regulatory uncertainties, simply because they prescribe particular technologies or practices from which market actors are not allowed to deviate. There is a literature in economics, however, suggesting that their very inflexibility makes them inefficient (Malueg 1990; Jaffe & Stavins 1995). More flexible policy instruments, by contrast, have the effect of promoting, rather than mandating behavioral change. No matter what the policy instrument employed, interventions that shift investment behaviour from currently low cost to currently high cost technologies run the risk of increasing short-term costs and energy security concerns for consumers (Del Rio and Gual, 2007; Manuel Frondel et al., 2008; M Frondel et al., 2010). In some cases long-term costs may be higher or lower, depending on how different technologies evolve over time (Williges et al., 2010; Reichenbach and Requate, 2012).

Typically, these instruments will influence the decisions of firms and private individuals, so that policy-makers need to anticipate how these agents will react to them.

This subsection is structured by considering two broad classes of interventions for targeting the energy supply: interventions that focus on emissions, by placing a market price or tax on CO_2 or other greenhouse gases; and interventions that promote research, development, deployment, and diffusion (RDD&D) of particular technologies. In both types of interventions, policy choices can be sensitive to uncertainties in technology costs, markets, and the state of regulation in other jurisdictions and over time. In the case of technology-oriented policy, choices are also sensitive to the risks that particular technologies present. We then describe instruments for reducing energy demand by focusing on lifestyle choice and energy efficient products and technologies. Finally, we briefly contrast the effects of uncertainties in the realm of climate adaptation with climate mitigation, recognizing that more detail on the former can be found in the report from Working Group II. At the outset we should note that few studies to date have incorporated how System 1 behaviour impacts on particular policy instruments, or on ways to encourage System 2 behaviour.

2.4.4.1 Instruments creating market penalties for GHG emissions

Market-based instruments place either a direct or opportunity cost on the emission of greenhouse gases. This increases the cost of energy derived from fossil fuels, potentially leading firms involved in the production and conversion of energy to invest in low carbon technologies. Considerable research prior to AR4 identified the differences between two such instruments—carbon taxes and cap and trade regimes—with respect to uncertainty. Since AR4, a research has started to examine the effects of regulatory risk and market uncertainty on one instrument or the other by addressing the following question: How is the mitigation investment decision is affected by uncertainty with respect to whether and to what extent a market instrument and well-enforced regulations will be in place in the future?

Much of this research has focused on uncertainty with respect to carbon prices under a cap and trade systems, given that a number of factors influence the relationship between the size of the cap and the market price. These include fossil fuel prices, consumer demand for energy, and economic growth more generally, each of which can lead to volatility in carbon market prices (Alberola et al., 2008; C. Carraro and Favero, 2009; Chevallier, 2009). Vasa and Michaelowa (2011) assessed the impact of policy uncertainty on carbon markets and found that the possibility of creating and destroying carbon markets with a stroke of a pen leads to extreme short-term rent seeking behaviour and high volatility in market prices. In their view, these negative effects can be reduced if climate policy decisions are long-term with clear consequences of non-compliance. Indeed, experience so far with the most developed carbon market—the European Emissions Trading System (ETS)—reveals high volatility marked by not-infrequent decreases of the price of carbon to very low values (Feng et al., 2011).

Numerous modelling studies have shown that regulatory uncertainty reduces the effectiveness of market-based instruments, in terms of promoting investments into low-carbon technologies. Assuming profit-maximizing firms, Yang et al., (2008) modelled optimal investment options under conditions of uncertainty in the future carbon price, with the results being sensitive to assumptions about relative technology prices. Blyth et al., (2007) modelled the behaviour of risk neutral profit maximizers, and found that including uncertainty with respect to future policy causes carbon prices to be between 16% and 37% higher than under conditions of policy certainty to achieve the same patterns of investment. Fuss et al.(2009) used a real options model to show that increased regulatory uncertainty leads to a slower pace of technological change, and higher cumulative emissions for a given expected carbon price.

The effects of future regulatory changes are greater the more frequent those changes are, even if the policy changes are small. In other words, less frequent but larger policy changes have less of a detrimental impact on overall emissions. Patiño-Echeverri et al., (2007, 2009) reached a similar conclusion by examining the effects of uncertain carbon prices on the actions of a risk neutral investor and then illustrated this effect by looking at decisions to invest in coal-fired power plants.

Reinelt and Keith (2007) found that regulatory uncertainty increases social abatement costs by as much as 50% by undertaking a similar analysis with respect to carbon capture and storage (CCS). They found that greater flexibility, in terms of the availability of low cost retrofit (adding CCS to an existing emissions source), reduces the additional costs associated with uncertainty. Zhao (2003) examines the effects of uncertainty in abatement cost on market based instruments employing either a carbon tax or a tradable permit market. He finds that firms' investment incentives into low carbon technology decreases with high uncertainty, but that the effect is greater when a carbon tax is imposed that under a tradable emissions permit market.

The above studies considered the case of risk neutral investors. Fan et al., (2010) examined the sensitivity of these results to increasing risk aversion, under two alternative carbon market designs: one in which carbon allowances were auctioned by the government to firms, and a second in which existing firms received free allowances due to a grandfathering rule. Under an auctioned system for carbon allowances, the effect of risk aversion is to reduce the effect of regulatory uncertainty in undermining the regime's effectiveness: increasing risk aversion leads to investments in low carbon technologies. In contrast, under a grandfathered market design the effect of uncertainty is to push investment behaviour close to what it would be in the absence of the carbon market: increasing risk aversion leads to more coal investment. Fan et al., (2012) replicated these results using a broader range of technological choices than in their earlier paper. Fuss et al., (2012) used a very different modelling methodology, based on real options theory, to reach similar conclusions by considering bio-energy producers in an auctioned permit scheme.

One option to reduce carbon price volatility is to set a cap or floor for that price to stabilize investment expectations (Jacoby and Ellerman, 2004; Philibert, 2009). Wood and Jotzo (2011) found benefit of setting such a price floor, in terms of increasing the effectiveness of the carbon price at stimulating investments, given a particular expectation of macroeconomic drivers (e.g., economic growth, fossil fuel prices, all of which influence the degree to which a carbon cap is a constraint on emissions).

Szolgayova et al., (2008) examined the effects of price cap using a real options model that specifically takes into account the value of waiting for more information before committing to a particular decision. They found the cap stabilized expectations but in the process lessened the effectiveness of an expected carbon price at altering investment behaviour. More specifically investments into low carbon technologies are undertaken only because of the possibility of very high carbon prices in the future. In another study based on the assumed presence of a rational actor, Burtraw et al. (2010) found that a symmetric safety valve that sets both a floor and a ceiling price outperforms a single sided safety valve in terms of both emissions reduction and economic efficiency. Murray et al. (2009) suggest that a reserve allowance for permits outperforms a simple safety valve in this regard.

Empirical research on the influence of uncertainty on carbon market performance has been constrained by the small number of functioning markets, thus making it difficult to infer effects from differences in market design. The few studies to date suggest that the details of market design can influence the perception of uncertainty, and in turn the performance of the market. More specifically, investment behaviour into the Clean Development Mechanism (CDM) has been influenced by uncertainties in terms of what types of projects are eligible (Castro and A. Michaelowa, 2011), and the actual number of Certified Emissions Reductions (CERs) that can be acquired from a given project (Richardson, 2008).

With respect to the European Union's Emission Trading System (ETS), researchers have observed that expected carbon prices do affect investment behaviour, but primarily for investments with very short amortization periods. High uncertainty with respect to the longer-term market price of carbon has limited the ETS from having an impact on longer-term investments such as R&D or new power plant construction (VH Hoffmann, 2007). Barbose et al. (2008) examined a region—the western United States—where no ETS was functioning but many believed that it would, and found that most utilities did consider the possibility of carbon prices in the range of $4 to $22 a ton. At the same time, the researchers could not determine whether this projection of carbon prices if an ETS were in place had an actual effect on their decisions. The researchers were unable to document the analysis underlying the utilities' investment decisions, and thus could not determine whether the degree of belief in the future carbon prices actually played a role.

2.4.4.2 Instruments promoting technological RDD&D

Several researchers suggest that future pathways for research, development, deployment, and diffusion(RDD&D) will be the determining factor for emissions reductions (Prins and Rayner, 2007; J. Lilliestam et al., 2012). There are a number of instruments that focus on this directly, by either supporting RDD&D with public funds by mandating particular technologies, or by guaranteeing a market for energy from renewable sources by fixing its price. Baker, Clarke and Shittu (2008) show that different policy instruments may provide incentives for firms not just to invest in particular low carbon technologies that already exist, but also to innovate new technologies that can be used in the future. In many cases, these instruments differ in the risks that investors face; hence their relative effectiveness is sensitive to market uncertainties.

The literature reviewed in the previous section, on market-based instruments, shows general agreement that their effectiveness at promoting RDD&D declines due to regulatory uncertainty. This has given rise to policy proposals to supplement a pure-market system with another instrument—such as a cap, floor, or escape valve—to reduce price volatility and stabilize expectations. By contrast, combining a market-based instrument with specific technology support can lead to greater volatility in the carbon price, even when there is very little uncertainty about which technologies will be assisted in the coming years (Blyth et al., 2009).

Several empirical studies have compared the effectiveness of market instruments with other instruments that provide direct stimulus to low carbon investments, at various stages in the RDD&D chain. Looking early in the technology development process, Bürer and Wüstenhagen (2009) surveyed *greentech* venture capitalists in the United States and Europe using a stated preference approach to identify which policy instrument or instruments would reduce the perceived risks of investment in a particular technology. They identified a strong preference on both continents, but in particular Europe, for feed-in tariffs over carbon markets and renewable quota systems. These empirical findings are consistent with a behavioural model of firm decision-making, in which perceived immediate risks play a central role in determining choices. In the spirit of System 1 behaviour, venture capital investors typically look for short- to medium-term returns on their investment, for which the presence of feed-in tariffs has the greatest positive effect. There is no literature suggesting ways of shifting such decision-making towards longer term strategies.

The comparative effectiveness of feed-in tariffs in reducing perceived risk appears also to be present later in the technology cycle during the project development stage. Butler and Neuhoff (2008), for example, compared the feed-in tariff in Germany with the quota system in the United Kingdom, and found the Germany system outperformed the UK system on two dimensions: stimulating overall investment quantity, and reducing costs to consumers. The primary driver was the effectiveness of the feed-in tariff at reducing risks associated with future revenues from the project investment, therefore making it possible to reduce the cost of project financing. Other researchers replicate this finding using other case studies (C Mitchell et al., 2006; Fouquet and TB Johansson, 2008). Even for a given technology support instrument, there are design choices that can affect investor risks. Held et al. (2006) identified patterns of success across a wide variety of policy instruments in Europe to stimulate investment in renewable energy technologies. They found that long-term regulatory consistency was vital for new technology development. Lüthi and Wüstenhagen (2011) surveyed investors with access to a number of markets, and found that they steered their new projects to those markets with feed-in tariff systems, as it was more likely than other policy instruments to reduce their risks. Lüthi (2010) compared policy effectiveness across a number of jurisdictions with feed-in tariffs, and found that above a certain level of return, risk-related factors did more to influence investment than return-related factors.

There have been a number of empirical papers examining risks and uncertainties that investors perceive as most important. Leary and Esteban (2009) found efforts to stimulate the development and deployment of wave and tide power was hampered by regulatory uncertainty with respect to coastal marine law as to where new developments could be sited. Komendantova et al. (2012) examined perceptions among investors in solar projects in North Africa, and found concerns about regulatory change and corruption were much greater than concerns about terrorism and technology risks. The same researchers modelled the sensitivity of required state subsidies for project development in response to these risks, and found the subsidies required to stimulate a given level of solar investment rose by a factor of three, suggesting large benefits from stemming corruption and stabilizing regulations (Komendantova et al., 2011).

Meijer et al. (2007) examined the perceived risks for biogas project developers in the Netherlands, and found technological, resource, and political uncertainty to be the most important concerns. In all of these examples, the absence of historical data makes it is difficult to undertake a convincing *objective* assessment of the actual risks facing investors. These studies are useful, not because they show whether investors act according to rational actor or behavioural models, but simply to document what are their major subjective concerns. These findings give policy-makers the opportunity to address these concerns.

Finally, policy discussions on particular technologies often revolve around the health and safety risks associated with technology options, transition pathways, and systems such as nuclear energy (N Pidgeon et al., 2008; Whitfield et al., 2009), coal combustion (GR Carmichael et al., 2009; Hill et al., 2009) and underground carbon storage (Itaoka et al., 2009; Shackley et al., 2009). There are also risks to national energy security that have given rise to political discussions advocating the substitution of domestically produced renewable energy for imported fossil fuels (J Eaves and S Eaves, 2007; Johan Lilliestam and Ellenbeck, 2011).

2.4.4.3 Energy efficiency and behavioral change

The reluctance of consumers to adopt energy efficient measures, such as compact fluorescent bulbs, energy efficient refrigerators, boilers and cooling systems as well as solar installations can be attributed to misperceptions of their benefits in reduced energy costs coupled with an unwillingness to incur the upfront costs of these measures triggered by System 1 behavior.

Gardner and Stern (2008) identified a list of energy efficient measures that could reduce North American consumers' energy consumption by almost 30% but found that individuals were not willing to invest in them because they have misconceptions about their effectiveness Larrick and Soll (2008) revealed that people in the U.S. mistakenly believe that gasoline consumption decreases linearly rather than nonlinearly as an automobile's miles per gallon increases. Other studies show that the general public has a poor understanding of the energy consumption associated with familiar activities (John D. Sterman and Sweeney, 2007). A national online survey of 505 participants by Attari et al. (2010) revealed that most respondents felt that measures such as turning off the lights or driving less were much more effective than energy efficient improvements in contrast to experts' recommendations.

There are both behavioral and economic factors that can explain the reluctance of households to incur the upfront costs of these measures. As the above studies indicate, individuals may underestimate the savings in energy costs from investing in energy efficient measures. In addition they are likely to have short time horizons and discount the future hyperbolically so that the upfront cost is perceived to be greater than expected discounted reduction in energy costs. Coupled with these descriptive models or choices that are triggered by System 1, households may have severe budget constraints that prohibit them from investing in these energy efficient measures. If they intend to move in several years and feel that the investment in the energy efficient measure will not be adequately reflected in an increase in their property value, then it is economically rational for them ***not*** to invest in these measures (H. Kunreuther, Pauly, et al., 2013).

To encourage households to invest in energy efficient measures, programs need to be developed to highlight the benefits from investing in the energy efficient measure in terms that the household can understand. To deal with budget constraints the upfront costs needs to be spread over time so the measures are viewed as economically viable and attractive. With respect to the first point, efforts are being designed to communicate information on energy use and savings from investing in more efficient measures (Abrahamse et al., 2005). The advent of the smart grid in Western countries, with its smart metering of household energy consumption and the development of smart appliances will make it feasible to provide appliance-specific feedback about energy use and energy savings to a significant number of consumers within a few years.

Developers of feedback interfaces of smart meters should be aware of behavioural responses to such information and take some lessons from OPower, a company that has been applying behavioural decision principles to the design of monthly bills, sent to residential utility customers. The company Opower has been highly successful in this regard by issuing reports that compare energy usage among neighbors with similarly-sized houses and also include targeted tips for households to lower their energy consumption to the "normal" neighborhood rate. Alcott (2011) estimates that Opower's Home Energy Report letters to residential utility customers that compare their electricity use to that of their neighbors reduces energy consumption by 2.0% in the targeted community. Social norms that encourage greater use of energy efficient technology at the household level, can also encourage manufacturers to invest in the R&D for developing new energy efficient technologies and by encouraging public sector actions such as well-enforced standards of energy efficiency as part of building sale requirements that had been practiced by the Davis, CA for thirty years (T. Dietz et al., 2013).

The Property Assessed Clean Energy (PACE) program in the United States is designed to address the budget constraint problem. t. Under this program, interested property owners opt-in to receive financing for improvements that is repaid through an assessment on their property taxes for up to 20 years. PACE financing spreads the cost of energy improvements such as weather sealing, energy efficient boilers and cooling systems, and solar installations over the expected life of these measures and allows for the repayment obligation to transfer automatically to the next property owner if the property is sold. PACE solves two key barriers to increased adoption of energy efficiency and small-scale renewable energy: high upfront costs and fear that project costs won't be recovered prior to a future sale of the property (H. Kunreuther et al., in press).

2.4.4.4 Adaptation and vulnerability reduction

Compared to investment in mitigation, investments in adaptation appear to be more sensitive to uncertainties in the local impacts associated with the damage costs of climate change. This is not surprising for two reasons. First, while both mitigation and adaptation may result in lower local damage costs associated with climate impacts, in the case of adaptation the benefits flow directly and locally from the action taken (Prato, 2008). Mitigation measures in one region or country, by contrast, deliver benefits that are global, and which are contingent on the actions of people in other places and in the future, rendering their local benefits more uncertain; one cannot simply equate marginal local damage costs with marginal mitigation costs, and hence the importance of uncertainty with respect to the local damage costs is diminished (Webster et al., 2003).

Second, politically negotiated mitigation targets, such as the 2°C threshold, appear to have been, to some extent, determined by what is feasible and affordable in terms of the pace of technological diffusion, rather than by an optimization of mitigation costs and benefits (Hasselmann et al., 2003; E. Baker et al., 2008; Hasselmann and Barker, 2008). Hence the temperature target, and all mitigation actions taken to achieve the target, would not be changed if the damage costs (local or global) were found to be somewhat higher or lower. Hence mitigation measures will be insensitive to such uncertainty. Adaptation decisions, in contrast face fewer political and technical constraints, and hence can more closely track what is needed in order to minimize local expected costs so will be more sensitive to the uncertainties surrounding damage costs (Patt et al., 2007, 2009).

There are two main exceptions to this, in which case decisions on adaptation policies and actions may be largely insensitive to uncertainties in climate on damages. The first exception is where adaptation is constrained by the availability of finance, such as international development assistance. Studies by the World Bank, OECD, and other international organizations have estimated the financing needs for adaptation in developing countries to be far larger than funds currently available (Agrawala and Samuel Fankhauser, 2008; Patt et al., 2010). In this case, adaptation actions become sensitive to higher-level decisions concerning the allocation of available finance across competing regions, a calculus that may depend on perceptions of relative vulnerability of people and organizations, rather than the attributed local impacts of climate change (Klein et al., 2007; M. Hulme et al., 2011). Funding decisions and political constraints at the national level can also constrain adaptation to an extent that choices no longer are sensitive to uncertainties with respects to local impacts (Suraje Dessai and Mike Hulme, 2004, 2007).

The other exception is where adaptation is severely constrained by a lack of local knowledge and analytic skill, restrictions on what actions can be taken and/or cultural norms (Brooks et al., 2005; Füssel and Klein, 2006; O'Brien, 2009; L Jones and Boyd, 2011). Adaptive capacity could be improved through investments in education, development of local financial institutes and property rights systems, women's rights, and other broad-based forms of poverty alleviation. There is a growing literature to suggest that such policies bring substantial benefits in the face of climate change. These benefits are relatively insensitive to the precise nature and extent of local climate impacts (C. Folke et al., 2002; Polasky et al., 2011). Such strategies are not designed to make people resilient to particular climate risks, but rather to reduce their vulnerability to a wide range of potential risks (Thornton et al., 2008; Eakin and Patt, 2011).

2.4.5 Public support and opposition to climate policy under uncertainty

Climate policy, while designed to minimize the risks associated with climate change itself, necessarily implies interventions into society that may carry negative effects at a number of different levels. At the national or regional scale, one of the possible negative impacts is diminished competitiveness for job creation. At the local level, negative effects can include adverse environmental impacts associated with particular kinds of energy infrastructure and higher local prices of energy. Individuals may feel that climate policies should be pursued, but at the same time may be concerned with short-run costs they will incur. In this sub-section, we review what is known about public support or opposition to climate policy in general, i.e. the goals, objectives, and instruments that public actors adopt, before turning to support and opposition to discrete infrastructure projects. Finally, we consider cross cutting issues associated with the science that is used to support or oppose specific policy proposals. Across all three areas, there are strong ties to the behavioural factors influencing System 1 thinking described in Section 2.2.

2.4.5.1 Popular support for climate policy

There is substantial evidence that people's support or opposition to proposed climate policy measures is determined primarily by emotional factors and their past experience rather than explicit calculations as to whether the personal benefits outweigh the personal costs. A national survey in the United States found that people's support for climate policy also depended on cultural factors, with regionally differentiated worldviews playing an important role (A. Leiserowitz, 2006), as did a cross national comparison of Britain and the United States (I. Lorenzoni and NF Pidgeon, 2006), and studies comparing developing with developed countries (Vignola et al., 2012).

One of the major determinants of popular support for climate policy is whether people have an underlying belief that climate change is dangerous. This concern can be influenced by both cultural factors and the methods of communication (J Smith, 2005; N Pidgeon and B. Fischhoff, 2011). Leiserowitz (2005) found a great deal of heterogeneity linked to cultural effects with respect to the perception of climate change in the United States. The use of language used to describe climate change—such as the distinction between "climate change" and "global warming"— play a role in influencing perceptions of risk, as well as considerations of immediate and local impacts (I. Lorenzoni et al., 2006). The portrayal of uncertainties and disagreements with respect to climate impacts was found to have a weak effect on whether people perceived the impacts as serious, but a strong effect on whether they felt that the impacts deserved policy intervention (Patt, 2007).

An important question related to climate change communication is whether the popular reporting of climate change through disaster scenarios has the effect of energizing people to support aggressive policy intervention, or to become dismissive of the problem. A study examining responses to fictionalized disaster scenarios found them to have differential effects on perceptions and support for policy, reducing people's expectation of the local impacts, while increasing their support for global intervention (T Lowe et al., 2006). Other studies found interactive effects: those who had low awareness of climate change became concerned by being exposed to disaster scenarios, while those with high awareness were dismissive of the possible impacts (Schiermeier, 2004).

Finally, the extent to which people believe it is possible to actually influence the future appears to be a major determinant of their support for both individual and collective action to respond to climate change. In the case of local climate adaptation, psychological variables associated with selfempowerment were found to have played a much larger role in influencing individual behavior than variables associated with economic and financial ability (Grothmann and Patt, 2005; Grothmann and Reusswig, 2006). With respect to mitigation policy, perceptions concerning the barriers to effective mitigation—belief that it was possible to respond to climate change—were found to be important determinants of popular support (I. Lorenzoni et al., 2007).

2.4.5.2 Local support and opposition to infrastructure projects

The issue of local support or opposition to infrastructure projects to implement climate policy is related to the role that perceived technological risks play in the process. This has been especially important with respect to nuclear energy, but is of increasing concern for carbon storage and renewable energy projects, and has become a major issue when considering expansion of low carbon energy technologies (Ellis et al., 2007; Van Alphen et al., 2007; Zoellner et al., 2008).

In the case of renewable energy technologies, a number of factors appear to influence the level of public support or opposition, factors that align well with a behavioural model in which emotional responses are highly contextual. One such factor is the relationship between project developers and local residents. Musall and Kuik (2011) compared two wind projects, where residents feared negative visual impacts. They found that the fear was less, and the public support for the projects higher when there was co-ownership of the development by the local community. A second factor is the degree of transparency surrounding project development. Dowd et al. (2011) investigated perceived risks associated with geothermal projects in Australia. Using a survey instrument, they found that early, transparent communication of geothermal technology and risks tended to increase levels of public support.

A third such factor is the perception of economic costs and benefits that go hand in hand with the perceived environmental risks. Zoellner et al. (2008) examined public acceptance of three renewable technologies (grid-connected PV, biomass, and wind). They found that perceived economic risks—in terms of higher energy prices—were the largest predictor of acceptance. Concerns over local environmental impacts, including visual impacts, were of concern where the perceived economic risks were high. Breukers and Wolsink (2007) also found that that the visual impact of wind turbines was the dominant factor in explaining opposition against wind farm. Their study suggests that public animosity towards a wind farm is partly reinforced by the planning procedure itself, such as where stakeholders perceive that norms of procedural justice are not being followed.

There have been many studies assessing the risks and examining local support for carbon capture and storage (CCS). According to Ha-Duong et al. (1997), the health and safety risks associated with carbon capture and transportation technologies differ across causal pathways but are similar in magnitude to technologies currently supported by the fossil-fuel industry. Using natural analogues, Roberts et al. (2011) concluded that the health risks of natural CO_2 seepage in Italy was significantly lower than many socially accepted risks. For example, it was three orders of magnitude lower than the probability of being struck by lightning.

Despite these risk assessments, there is mixed evidence of public acceptance of CO_2 storage . For example, a storage research project was authorized in Lacq, France, but another was halted in Barendreich, The Netherlands due to public opposition. On the other hand, Van Alphen et al. (2007) evaluated the concerns with CCS among important stakeholders, including government, industry, and NGO representatives and found support if the facility could be shown to have a low probability of leakage and was viewed as a temporary measure.

Wallquist et al. (2012) used conjoint analysis to interpret a Swiss survey on the acceptability of CCS and found that concerns over local risks and impacts dominated the fears over the long-term climate impacts of leakage. The local concerns were less severe, and the public acceptance higher, for CCS projects combined with biomass combustion, suggesting that positive feelings about removing CO_2 from the atmosphere, rather than simply preventing its emission into the atmosphere, influences perceptions of local risks. Terwei et al. (2011) found that support for CCS varied as a function of the stakeholders promoting and opposing it, in a manner similar to the debate on renewable energy. Hence, there was greater support of CCS when its promoters were perceived to be acting in the public interest rather than purely for profit. Those opposing CCS were less likely to succeed when they were perceived to be acting to protect their own economic interests, such as property values, rather than focusing on environmental quality and the public good.

In the period between the publication of AR4 and the accident at the Fukushima power plant in Japan in March 2011, the riskiness of nuclear power as a climate mitigation option has received increasing attention. Socolow and Glaser (2009) highlight the urgency of taking steps to reduce these risks, primarily by ensuring that nuclear fuels and waste materials are not used for weapons production. A number of papers examine the perceived risks of nuclear power among the public. In the United States, Whitfield et al. (2009) found risk perceptions to be fairly stable over time, with those people expressing confidence in “traditional values” perceiving nuclear power to be less risky. In the United Kingdom, Pidgeon et al. (2008) found a willingness to accept the risks of nuclear power when it was framed as a means of reducing the risks of climate change, but that this willingness largely dissipated when nuclear power was suggested as an alternative to renewable energy to accomplish this same objective.

2.4.5.3 Uncertainty and the science policy interface

The linear model of linking science to policy, aptly described by the phrase “speaking truth to power” (Price, 1965), presumes that scientific facts can be produced independently of social and political considerations and can serve as unproblematic inputs to policy. This model implies that public refusal to accept a firm scientific consensus must be the result of efforts by political interests to undermine the truth. Thus, public opposition to the IPCC consensus on anthropogenic climate change has been attributed to doubt raised by biased, industry-sponsored scientists with little regard for the truth (Oreskes and Conway, 2010).

Research on the relationship between science and policy, however, rejects the linear model as simplistic, concluding that it does not adequately account for the complexity of science-based policymaking (Sheila Jasanoff, 1990; Pielke, 2007; Shackley et al., 2009). Linking science to policy is better understood as a recursive activity, involving analysis as well as deliberation (Stern and Fineberg, 1996) so as to bridge uncertainties, accommodate multiple viewpoints, and establish trust across heterogeneous communities. Accordingly, attention has increasingly focused on the role of institutions and policy practices in translating science to policy in ways that advance the public good.

To understand the nature of such translation, the concept of uncertainty needs to be examined more closely. Analysts have called attention to several different forms of uncertainty affecting the science-policy relationship. These can be summarized as follows:

- **Paradigmatic uncertainty.** This results from the absence of prior agreement on the framing of problems, on methods for scientifically investigating them, and on how to combine knowledge from disparate research traditions. Such uncertainties are especially common in cross-disciplinary, application-oriented research and assessment for meeting policy objectives (Gibbons, 1994; Nowotny et al., 2001).

- **Epistemic uncertainty.** This results from lack of adequate knowledge to characterize the nature and probability of outcomes. Stirling (2007) further distinguishes between uncertainty (insufficient knowledge to assess probabilities), ambiguity (insufficient knowledge about possible outcomes), and ignorance (insufficient knowledge of likely outcomes and their probabilities). Others have noted that producing more knowledge may exacerbate uncertainty, especially when actors disagree about how to frame a problem for scientific investigation (Beck, 1992; Gross, 2010).

- **Translational uncertainty.** This results from scientific findings that are incomplete or conflicting, so that they can be invoked to support divergent policy positions (Sarewitz, 2010). In such circumstances, protracted controversy often occurs as each side challenges the methodological foundations of the other's claims in a process called "experimenters' regress" (Collins, 1985).

Institutions that link science to policy must grapple with all of the above forms of uncertainty, often simultaneously. Because their work cuts across conventional lines between science and politics, these institutions have been called "boundary organizations" (Guston, 2001) and their function has been termed "hybrid management" (C Miller, 2001). Straddling multiple worlds, science-policy institutions are required to meet both scientific and political standards of accountability. Whereas achieving scientific consensus frequently calls for bounding and closing down disagreements, achieving political legitimacy requires opening up areas of conflict in order to give voice to divergent perspectives.

The task of resolving conflicts in policy-relevant science is generally entrusted to multidisciplinary expert bodies. These organizations are best suited to addressing the paradigmatic uncertainties that arise when problems are novel or when synthesis is required across fields with different standards of good scientific practice. Bridging epistemic and translational uncertainties, however, imposes added demands. For expert advisory bodies to be viewed as legitimate they must represent all relevant viewpoints in a politically acceptable manner (Sheila Jasanoff, 1990, 2005). What counts as acceptable varies to some degree across national decision-making cultures, each of which place different weights on experts' personal integrity, the reliability of their disciplinary judgments, and their ability to forge agreement across competing values (Shiela Jasanoff, 2005, pp. 209–224).

To achieve legitimacy, institutions charged with linking science to policy must also open themselves up to public input at one or more stages in their deliberations. This process of "extended peer review" (Funtowicz and Ravetz, 1992) is regarded as necessary for the production of "socially robust knowledge," i.e., knowledge that can withstand public scrutiny and scepticism (Gibbons, 1994). Procedures that are sufficient to produce public trust in one political context may not work in others because national political cultures are characterized by different "civic epistemologies," i.e., culturally specific modes of generating and publicly testing policy-relevant knowledge (Sheila Jasanoff, 2005).

International and global scientific assessment bodies confront additional problems of legitimacy because they operate outside long-established national decision-making cultures and are accountable to publics subscribing to different civic epistemologies (Sheila Jasanoff, 2010). The temptation for such bodies has been to seek refuge in the linear model in the hope that the strength of their internal scientific consensus will be sufficient to win wide political buy-in. The recent research on linking science to policy suggests otherwise.

2.5 Gaps in Knowledge

- Systematically examine cross-cultural differences in human perception and reaction to climate change and climate change response options focusing on a representative range of countries with different levels of economic development and different cultures.

- Understand more fully the effect that taking some action that mitigates or protects against climate change risks have on subsequent behavior?

- Determine where people exhibit status-quo biases when it comes to accepting technological innovation related to climate change mitigation, including carbon capture and storage? If so, what actions can policy makers take to assuage people's risk aversion or loss aversion concerns in this domain?

- How to capture and represent dependence in high dimensional distributions, taking into account features like tail dependence and micro correlation
- How to characterize fat tails in empirical distributions, how to address issues like covariates, regression, dependence.
- Using integrated assessment models to quantify the value of new climate observing systems
- How people could employ System 1 and System2 processes to make improved decisions and choices with respect to decisions involving climate change.
- Determine the effectiveness of social norms in promoting favorable actions for dealing with climate change in the long-term
- Determine the effectiveness of experiential methods like simulations, games, and movies in improving public understanding and perception of climate change processes
- Developing incentives coupled with well-enforced standards and regulations that lead foster long-term strategies such as investment in energy efficient technologies for addressing climate change.
- Examining special problems faced by developing countries in dealing with risk and uncertainty with respect to climate change policies.
- Determine the extent to which robust decision making can address the challenges by researchers with respect to the tail of the distribution with respect to the impact of climate change
- Better understanding how investors rank different risks associated with new technologies, and the policies and instruments that can reduce those risks that matter the most
- Increase our understanding of the environmental and social risks associated with new technologies,
- Understand the risks to energy systems, energy markets, and the security of energy supply should there be a future energy system in which there are no net atmospheric carbon emissions.

Appendix: Metrics of uncertainty and risk

A unified approach for all three WGs

The goal of any IPCC report is to inform the decision-making process in the context of climate change, its impacts, and response strategies. Different disciplines contribute to this task, each shaped by different historically grown standards and procedures of approval of scientific findings. Since all these methodologically diverse disciplines are supposed to interactively contribute to answering pertinent overarching questions, the IPCC has used “calibrated language” to characterize the scientific understanding and associated uncertainties underlying assessment findings (Moss and Schneider, 2000). In fact in AR4, all three Working Groups employed calibrated uncertainty language for the first time (MD Mastrandrea et al., 2011) but used different metrics. For example, Working Group III used only qualitative summary terms.

In preparation for AR5, an IPCC Cross-Working Group meeting on Consistent Treatment of Uncertainties took place in July 2010. Following this meeting, a writing team, including a Co-Chair and LAs from each IPCC Working Group (including an LA of this Chapter), scientists from the Technical Support Units, and other experts in treatment of uncertainties drafted the Guidance Note (“GN”) for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties (M Mastrandrea et al., 2010). This Appendix present key elements of the GN and interpret them to frame the handling of uncertainty and risk in a consistent manner throughout the AR5-WGIII.

Key concepts

The GN recommends organizing the reporting of certainty and/or uncertainty with respect to so-called key findings (to be defined below) using the categories evidence, agreement, confidence, probability and traceable account.

A key finding is a “conclusion of the assessment process that the author team may choose to include in the chapter’s Executive Summary…” (M11)

“Types of evidence include, for example, mechanistic or process understanding, underlying theory, model results, observational and experimental data, and formally elicited expert judgment. The amount of evidence available can range from small to large, and that evidence can vary in quality. Evidence can also vary in its consistency, i.e., the extent to which it supports single or competing explanations of the same phenomena, or the extent to which projected future outcomes are similar or divergent.

The degree of agreement is a measure of the consensus across the scientific community on a given topic and not just across an author team. It indicates, for example, the degree to which a finding follows from established, competing, or speculative scientific explanations. Agreement is not equivalent to consistency. Whether or not consistent evidence corresponds to a high degree of agreement is determined by other aspects of evidence such as its amount and quality; evidence can be consistent yet low in quality.” (M11)

The GN further introduces the central concept of confidence as a subjective function of evidence and agreement. “A level of confidence provides a qualitative synthesis of an author team’s judgment about the validity of a finding; it integrates the evaluation of evidence and agreement in one metric.” (M11) Hence, “confidence” expresses the extent as to which the IPCC authors do in fact support a key finding. If confidence was "large enough" (to be detailed below), the GN suggests further specification of the degree of confidence in the key findings in probabilistic terms[3]

Ebi (2011) (and in a similar vein also Jones (2011)) suggests that "theory" be treated as a third, independent input – in addition to evidence and agreement – for "confidence." When there are insufficient confidence levels (given a certain decision problem at stake), the reader would systematically receive more detailed information as to why there was insufficient data. Cases where theory and empirical data can support a confidence level needs to be distinguished from situations where this is not the case. We regard the GN mapping to be logically consistent with Ebi's model. Authors always have the freedom to provide more information than requested by the GN, in the form of a traceable account (see § below).

To conclude the list of categories, "the author team's evaluation of evidence and agreement provides the basis for any key findings it develops and also the foundation for determining the author team's degree of certainty in those findings. The description of the author team's evaluation of evidence and agreement is called a traceable account in the GN. Each key finding presented in a chapter's Executive Summary will include reference to the chapter section containing the traceable account for the finding." (M11)

General recommendations of the GN

Before elaborating on a sequence of practical recommendations with respect to the reporting of cases of increasing precision, the GN provides a list of the following items:

- There is a fundamental and delicate trade-off between generality and precision of a statement the authors should keep in mind: "It is important for author teams to develop findings that are general enough to reflect the underlying evidence but not so general that they lose substantive meaning."
- The GN also elucidates on the treatment of causal chains: "For findings (effects) that are conditional on other findings (causes), consider independently evaluating the degrees of certainty in both causes and effects, with the understanding that the degree of certainty in the causes may be low. In particular, this approach may be appropriate for high-consequence conditional outcomes." For example, authors should be aware that composite probabilities in a causal chain are by definition lower than individual probabilities.
- "Findings can be constructed from the perspective of minimizing false positive (Type I) or false negative (Type II) errors, with resultant tradeoffs in the information emphasized."
- The GN recommends taking more of a risk-management perspective than in AR4. "Sound decision making that anticipates, prepares for, and responds to climate change depends on information about the full range of possible consequences and associated probabilities. Such decisions often include a risk management perspective. Because risk is a function of probability and consequence, information on the tails of the distribution of outcomes can be especially important. Low-probability outcomes can have significant impacts, particularly when characterized by large magnitude, long persistence, broad prevalence, and/or irreversibility. Author teams are therefore encouraged to provide information on the tails of distributions of key variables, reporting quantitative estimates when possible and supplying qualitative assessments and evaluations when appropriate."
- The treatment of uncertainty is discussed GN1-5:

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[3] Hereby a reader of the GN should not be confused by the fact that whenever the GN employ the term "likelihood" they refer to what statisticians do call "probability." This is distinct from the "likelihood *function*" as utilized within the Bayesian formula.

  - GN1: “At an early stage, consider approaches to communicating the degree of certainty in key findings in your chapter using the calibrated language described below. Determine the areas in your chapter where a range of views may need to be described, and those where the author team may need to develop a finding representing a collective view. Agree on a moderated and balanced process for doing this in advance of confronting these issues in a specific context.”
  - GN2: “Be prepared to make expert judgments in developing key findings, and to explain those judgments by providing a traceable account: a description in the chapter text of your evaluation of the type, amount, quality, and consistency of evidence and the degree of agreement, which together form the basis for a given key finding. Such a description may include standards of evidence applied, approaches to combining or reconciling multiple lines of evidence, conditional assumptions, and explanation of critical factors. When appropriate, consider using formal elicitation methods to organize and quantify these judgments (Morgan et al., 2009).
  - GN3: “Be aware of a tendency for a group to converge on an expressed view and become overconfident in it (Morgan and Henrion, 1990). Views and estimates can also become anchored on previous versions or values to a greater extent than is justified. One possible way to avoid this would be to ask each member of the author team to write down his or her individual assessments of the level of uncertainty before entering into a group discussion. If this is not done before group discussion, important views may be inadequately discussed and assessed ranges of uncertainty may be overly narrow (Straus et al., 2009). Recognize when individual views are adjusting as a result of group interactions and allow adequate time for such changes in viewpoint to be reviewed.” In fact, Morgan (2011) suggests that “once they have read the relevant literature, but before they begin discussions to reach a group consensus, each member of an authoring team could be asked to engage in an expert elicitation about the value of a few key coefficients. The range of results could then serve as an input to inform the process of developing a group consensus judgment.”
  - GN4: “Be aware that the way in which a statement is framed will have an effect on how it is interpreted (e.g., a 10% chance of dying is interpreted more negatively than a 90% chance of surviving; (Kahneman and Tversky, 1979). Consider reciprocal statements to avoid value-laden interpretations (e.g., report chances both of dying and of surviving).”
  - GN5: “Consider that, in some cases, it may be appropriate to describe findings for which evidence and understanding are overwhelming as statements of fact without using uncertainty qualifiers.”
- The review procedure is covered by GN6 and GN7:
  - GN6: “Consider all plausible sources of uncertainty. Experts tend to underestimate structural uncertainty arising from incomplete understanding of or competing conceptual frameworks for relevant systems and processes (Morgan et al., 2009). Consider previous estimates of ranges, distributions, or other measures of uncertainty, their evolution, and the extent to which they cover all plausible sources of uncertainty.”
  - GN7: “Assess issues of uncertainty and risk to the extent possible. When appropriate probabilistic information is available, consider ranges of outcomes and their associated probabilities with attention to outcomes of potential high consequence…” .

Building on these more general statements, the GN then defines a sequence of steps for determining the degree of certainty in a specific finding. M11 further spells out the recommendations as follows:

“The first step in this process (the upper left of Fig. 2.4) is for the author team to consider the appropriate summary terms corresponding to its evaluation of evidence and agreement. As outlined in GN8 and depicted in Fig. 2.5, the summary terms for evidence (characterizing the type, amount, quality, and consistency of evidence) are limited, medium, or robust. The GN indicates that evidence is generally most robust when there are multiple, consistent independent lines of high-quality evidence. The summary terms for the degree of agreement are low, medium, or high.”

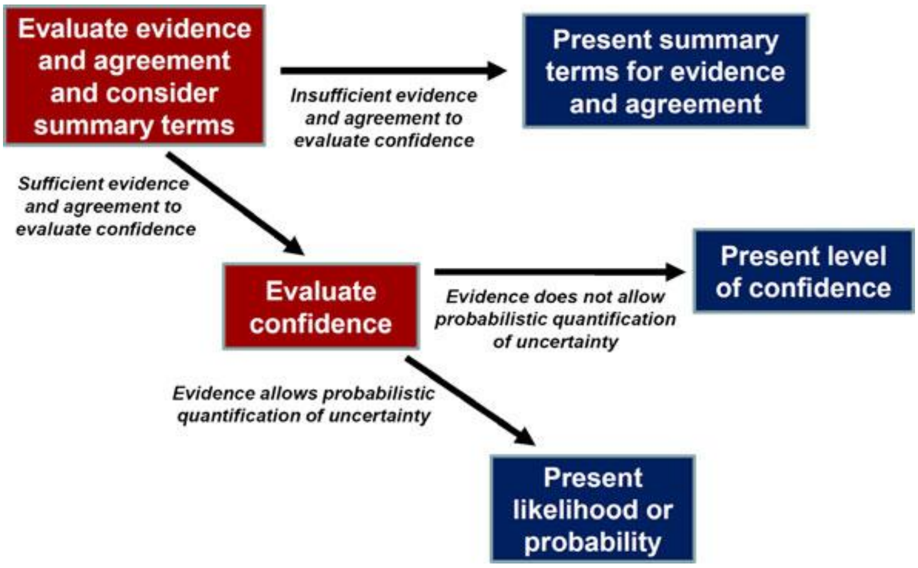
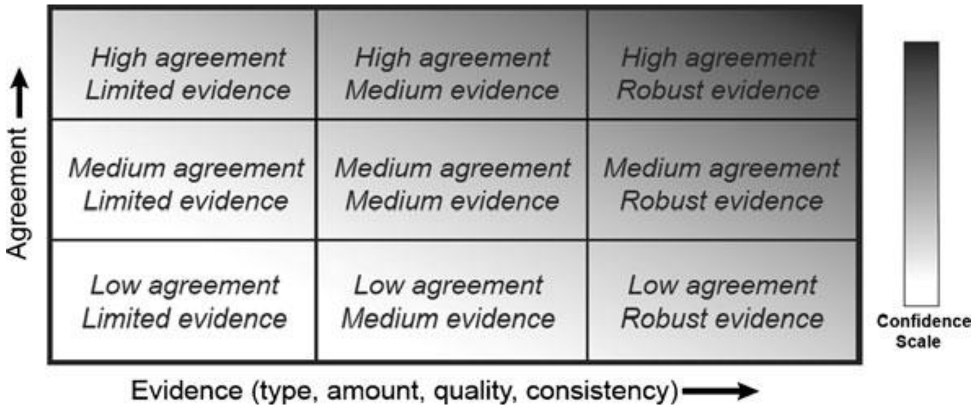


Figure 2.4 Process for evaluating and communicating the degree of certainty in key findings.

As the second step in determining the degree of certainty in a key finding, the author team decides whether there is sufficient evidence and agreement to evaluate confidence. This task is relatively simple when evidence is robust and/or agreement is high. For other combinations of evidence and agreement, the author team should evaluate confidence whenever possible. For example, even if evidence is limited, it may be possible to evaluate confidence if agreement is high. Evidence and agreement may not be sufficient to evaluate confidence in all cases, particularly when evidence is limited and agreement is low. In such cases, the author team instead presents the assigned summary terms as part of the key finding. The qualifiers used to express a level of confidence are very low, low, medium, high, and very high. Figure 2.5 depicts summary statements for evidence and agreement and their flexible relationship to confidence.” (M11)

The GN deliberately abstains from defining the functional mapping from evidence and agreement on confidence, as this represents a highly complex process that may vary from case to case. Instead authors are encouraged to justify their mapping as part of the traceable account. The GN point out that normally, findings of (very) low confidence shall not be reported, except for “areas of major concern”, if carefully explained. This again points to an elevated risk perspective in the GN.

The nine possible combinations of summary terms for evidence and agreement are shown in Figure 2.5 along with their relationship to the confidence scale. Confidence generally increases towards the top-right corner as suggested by the increasing strength of shading. By construction, confidence increases when there is higher agreement and more robust evidence.

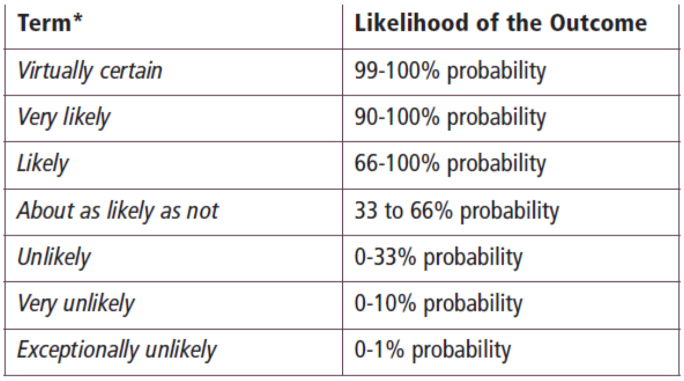


High agreement *Limited evidence*	*High agreement* *Medium evidence*	*High agreement* *Robust evidence*
Medium agreement *Limited evidence*	*Medium agreement* *Medium evidence*	*Medium agreement* *Robust evidence*
Low agreement *Limited evidence*	*Low agreement* *Medium evidence*	*Low agreement* *Robust evidence*

Figure 2.5 A depiction of evidence and agreement statements and their relationship to confidence. Figure reproduced and legend adapted from the GN.

To communicate probability or likelihood, the GN encourages one to use the following coarse-graining "calibrated language" (see Table 2.3 below) that is empirically supported as noted by (Morgan, 2011):

Table 2.3. Calibrated language in case likelihood is communicated in non-numerical terms in AR5 (M11).



Term*	Likelihood of the Outcome
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33 to 66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

Depending on the audience, either this calibrated language or the original numerical value (or an interval of values) might have higher chances that the statement is interpreted correctly (David V. Budescu et al., 2009). The safest option would be to note both.

The GN notes that authors should report a certain category of precision only if the requirements for lower categories are fulfilled as well. Overly precise statements on probability are meaningless if they cannot be justified on the basis of underlying processes. Each category of precision is illustrated by an example within the context of WGIII.

GN11: "Characterize key findings regarding a variable…using calibrated uncertainty language that conveys the most information to the reader, based on the criteria (A-F) below . These criteria provide guidance for selecting among different alternatives for presenting uncertainty, recognizing that in all cases it is important to include a traceable account of relevant evidence and agreement in your chapter text.

Category A: A variable is ambiguous, or the processes determining it are poorly known or not amenable to measurement:

Confidence should not be assigned; assign summary terms[4] for evidence and agreement […]. Explain the governing factors, key indicators, and relationships. If a variable could be either positive or negative, describe the pre-conditions or evidence for each."

Example: Within certain time windows it was not clear whether prices for photovoltaic showed a continued negative trend or whether the trend was reversed in response to feed-in tariffs in some European countries.

Category B: "The sign of a variable can be identified but the magnitude is poorly known:

Assign confidence when possible; otherwise assign summary terms for evidence and agreement […]. Explain the basis for this confidence evaluation and the extent to which opposite changes would not be expected."

Example: Most experts would agree that the global adaptive capacity for the shift in rainfall patterns is positive. But the magnitude might be difficult to determine without more explicit models from the field of development economics.

Category C: "An order of magnitude can be given for a variable:

Assign confidence when possible; otherwise assign summary terms for evidence and agreement […]. Explain the basis for estimates and confidence evaluations made, and indicate any assumptions. If the evaluation is particularly sensitive to specific assumptions, then also evaluate confidence in those assumptions."

Example: Many WGIII authors may conclude that the order of magnitude of global mitigation costs is known as a function of a prespecified target. However, if all social frictions (in a society "not yet prepared to mitigate") were taken into account, costs might be considerably higher.

Category D: "A range can be given for a variable, based on quantitative analysis or expert judgment:

Assign likelihood or probability for that range when possible; otherwise only assign confidence […]. Explain the basis for the range given, noting factors that determine the outer bounds. State any assumptions made and estimate the role of structural uncertainties. Report likelihood or probability for values or changes outside the range, if appropriate."

Example: Based on a comparison of models, intervals on mitigation costs under first-best conditions can be given.

Category E: "A likelihood or probability can be determined for a variable, for the occurrence of an event, or for a range of outcomes (e.g., based on multiple observations, model ensemble runs, or expert judgment):

Assign a likelihood for the event or outcomes, for which confidence should be "high" or "very high" […]. In this case, the level of confidence need not be explicitly stated. State any assumptions made and estimate the role of structural uncertainties. Consider characterizing the likelihood or probability of other events or outcomes within the full set of alternatives, including those at the tails."

Example: See example below in F.

Category F: "A probability distribution or a set of distributions can be determined for the variable either through statistical analysis or through use of a formal quantitative survey of expert views:

Present the probability distribution(s) graphically and/or provide a range of percentiles of the distribution(s), for which confidence should be "high" or "very high" (see Paragraphs 8-10). In this case, the level of confidence need not be explicitly stated. Explain the method used to produce the

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[4] A summary term is of one of the qualitative scales (*Agreement* or *Evidence*) in Fig. 2.4

probability distribution(s) and any assumptions made, and estimate the role of structural uncertainties. Provide quantification of the tails of the distribution(s) to the extent possible."

Difference between E and F: Category F in its pure form requires a probability measure for the entire domain of a variable. Category E requires less information than F, as certain quantiles are sufficient. Nevertheless, for both categories, one may require a set (consisting of more than one element) of probability measures rather than a single one.

Example: Experience curves have been evaluated using econometric methods to derive probabilistic statements with respect to learning curve coefficients.

The GN concludes:

"In summary, communicate uncertainty carefully, using calibrated language for key findings, and provide traceable accounts describing your evaluations of evidence and agreement in your chapter."

Category F in its pure form fits the requirements of the "standard decision model" in the "tools" section. For all other cases, workarounds need to be defined if the uncertainties reported were to be put in a decision context. Non-probabilistic criteria like dominance, minimax, min-regret and others should be considered, but might not utilize all the information content provided by the data. Defining decision criteria that fulfill desirable axioms such as time consistency is a field of active research.

WGIII perspective

A major part of AR5-WGIII will report on scenarios characterized by epistemic uncertainties with respect to some parameters and the structure of the model. In evaluating a mitigation policy it will be important first to separate the effects induced by different normative and other "external" scenario assumptions before model results are pooled.

To date, our understanding of the relationship between a macroeonomic model and 'reality' has not been characterized by a formal relationship that enables one to specify error terms but by more informal models. M11 also notes that it is often not clear what facts should be used to calibrate the model and advocates experiments to compare models. This may increase our understanding of the underlying philosophies in model construction so one can stronger involve hindcasting experiments in the future.

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