IPCC WGII Fourth Assessment Report – Draft for Expert Review

Chapter 2 – New Assessment Methodologies and the Characterisation of Future Conditions

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Contents

Executive Summary

This chapter describes the significant developments in methods of climate change impact, adaptation and vulnerability (CCIAV) assessment methods since the TAR that feature in this Report. It also introduces the main scenarios and approaches to scenario construction that are used to characterise future conditions in the studies reported in this volume.

A rich array of approaches to assessment is becoming available in response to policy needs. These approaches can be classified according to their subject matter, and are here classified as natural hazard, vulnerability/resilience and policy-driven approaches. While top-down, scenario-driven assessments that require downscaling from coarse to fine scales and which are projected though one or more impact models, are those undertaken most often, other permutations are becoming more common, in particular bottom-up, vulnerability-driven approaches at local scale. There continue to be ambiguities in the common distinction between "top-down" and "bottom-up" approaches to the assessment of climate change impacts, adaptation and vulnerability (CCIAV). These terms may refer to spatial scale (e.g. proceeding from global to local or vice versa), subject matter (e.g. scenario-, vulnerability-, hazard-, or sustainability-driven) or chronology (e.g. a projection forward in time or a back-calculation of pathways that fulfil a prescribed target) or combinations of these.

Risk management frameworks are useful methods for assessing and analysing the risks associated with climate change. Risk management combines concepts of hazard, consequence, probability and treatment of risk, where climate change and its impacts can be regarded as the hazard, vulnerability as the consequence, the likelihood of exceeding given levels of climate change (including climate extremes) as probability and mitigation and adaptation options as risk treatment. The major advantages of risk management approaches are that they have formal methods for dealing with uncertainty, can accommodate different questions, approaches and methods, can consider both the upside (opportunities) and downside (avoiding harm) of risk and have greater flexibility than forecast–response methods. Recent steps to standardise risk management internationally promise to remove some of the confusion caused by different nomenclature and approaches.

The coping range of climate is defined as the capacity of systems to accommodate variations in climatic conditions. Since the TAR this concept has been developed to incorporate concepts of adaptation, planning and policy horizons, and likelihood – largely within a risk management context. The coping range provides a template that is particularly suitable for understanding the relationship between climate hazards and society. It can be utilised in risk assessments to provide a means for communication and, in some cases, can be used as the basis for analysis.

Stakeholder participation is crucial for successful climate risk treatment. Stakeholders are individuals or groups who have anything of value that may be affected by climate change or by the actions taken to manage the ensuing risks of climate. People’s knowledge and expertise comprise the principle resource for adapting to the impacts of climate change, and stakeholders are seen as crucial in assessing the needs for developing policies and measures to adapt to climate change, because they are those who will be most affected and need to carry out adaptation. These needs have been recognised in emerging regional and national approaches to assessing climate impacts and adaptation. Six levels of stakeholder participation can be identified: participation in giving information, participation by consultation, functional participation, interactive participation, self-mobilisation, and catalysing change. Stakeholders can also provide valuable information for defining key thresholds that are needed in undertaking risk assessments. A growing literature is also investigating the role of stakeholders in developing and understanding adaptive capacity.

The formal management of uncertainty for decision-making is becoming central to CCIAV assessment. Managing uncertainty refers to taking account of uncertainty and appropriately integrating it into policy and decision- – making processes. One strategy is to consider decision approaches that are robust against the complex and deep uncertainties associated with climate change. The focus here is to seek strategies that are relatively insensitive to uncertainty about future climate change. A second approach aims to improve decision-makers' capacity to handle risk about climate change by advocating a decision framework that explicitly considers all relevant uncertainties, including uncertainties not only in future climate but also its impacts. A refinement of this is an impacts threshold exceedence approach to climate change risk assessment in which thresholds of acceptable damage or loss are established which define the coping range of the system. Adaptation strategies are then evaluated according to their effectiveness at maintaining the level of damage at or within the acceptable thresholds or coping range.

SRES-based scenarios. The publication of the IPCC Special Report on Emissions Scenarios (SRES) in 2000 presented a useful starting point for impact assessors to construct a range of mutually consistent regional climate and non-climatic scenarios. However, the SRES framework is generic and qualitative: it does not provide descriptions of regional changes at the detail required for most impact assessments. Thus, in developing scenarios for individual sectors and regions within the SRES framework, it is necessary both to interpret regional scale and sector-based driving factors and to quantify the effects of these drivers. A range of methods have been applied to downscale the SRES storylines to regions, including stakeholder participation, expert judgement, modelling, and disaggregation. New regional scenarios have been developed of socio-economic development (e.g. population, economic activity), adaptive capacity (e.g. standards of coastal protection, farm-level management responses), land use and land cover, atmospheric composition (e.g. CO_2 concentration, tropospheric ozone and N-deposition), climate, sea-level and many have been applied in impact studies reported in this volume.

Mitigation/stabilisation scenarios. Mitigation scenarios assume targeted reductions in greenhouse gas (GHG) emissions. Stabilisation scenarios make up an important sub-set of mitigation scenarios, describing futures in which emissions reductions are undertaken so that greenhouse gas concentrations (most commonly CO_2 concentration) or global average temperature change do not exceed a prescribed limit. Special attention has been given to stabilisation scenarios in the literature because they represent a common interpretation of the objective of the Framework Convention on Climate Change, which is to "stabilise greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system". Impact assessment for mitigation scenarios is important because it provides crucial information for weighing tradeoffs between the potential costs of mitigation and the impacts of climate change. There are relatively few regional climate scenarios that are forced by stabilisation scenarios. However, climate projections based on low-end SRES emissions scenarios that stabilise by the end of the 21st century (though they assume no explicit climate policy) have been advocated as surrogates for stabilisation scenarios down to about 550 ppm CO_2. No SRES surrogates exist for levels below 550 ppm. More problematic is the identification of regional socio-economic, land use and other scenarios that are commensurate with a mitigated future. New stabilisation scenarios for multiple GHGs have been evaluated in the AR4, and new climate model simulations assuming different stabilisation levels have been reported. However, these are not yet available for impact studies. Hence, the scope for detailed regional impact studies assuming GHG stabilisation is limited, and there are few published studies.

Probabilistic representations of climate change are increasingly being adopted in CCIAV assessments. Since the TAR, many studies have produced probabilistic representations of climate change, which can be useful for impact assessment. Some studies consider the "integrated climate change context" in that they include uncertainties in the climate system (usually represented through key climate model parameters such as climate sensitivity) as well as uncertainties in future emissions (which are more controversial), while others consider only subcomponents of the problem. Key choices in these studies are which components of the problem to treat as uncertain, and how to define the probability density functions (pdfs) for those components. Most of this research has focused on the global scale, and much less has been produced on the regional scale, a scale, arguably of greater relevance for use in impact assessment and risk management.

Other global scenarios. The SRES emissions scenarios represent only a small subset of all available scenarios of global futures, albeit specifically targeted at the climate issue. Some other global scenario-building exercises with an environmental focus include: the Global Scenarios Group (GSG) at the Stockholm Environment Institute, the third Global Environmental Outlook (GEO-3), organized by the United Nations Environment Programme (UNEP) and currently being updated to GEO-4, the World Business Council on Sustainable Development (WBCSD), Organisation for Economic Co-operation and Development (OECD), the World Water Vision (WWV) and the Millennium Ecosystem Assessment (MA). There are overlaps between several of these. The issue of how to integrate information at different scales has been addressed by the MA, which has attempted to nest scenarios within each other to create a set of multi-scale scenarios.

2.1 Introduction

Accurate and reliable assessments of climate change impacts, adaptation and vulnerability (CCIAV) are becoming increasingly important for researchers and policy makers alike, as climate change becomes more apparent and the likely need for response measures becomes more acute. In previous years, Working Group II[1] of the Intergovernmental Panel on Climate Change (IPCC) has devoted a Special Report and two chapters to assessment methods (Ahmad; Warrick *et al*. 2001: Carter; Parry *et al*. 1996: IPCC 1994). Moreover, recognising the fundamental importance of scenario development in most CCIAV assessments, the IPCC Third Assessment Report (TAR) included a broad treatment of this topic (Carter; La Rovere *et al*. 2001: Mearns; Hulme *et al*. 2001), which built on earlier descriptions of climate scenario development (IPCC-TGCIA, 1999). These contributions provide detailed descriptions of assessment methods and scenarios, which are not repeated in the current assessment.

Scenarios of the future and the CCIAV procedures that apply them are becoming increasingly interdependent. We can identify three main strands in these developments:

a) Scientific improvements: improved knowledge, methods and tools are increasing the scope and complexity of CCIAV assessments.
b) Policy relevance: a broader range of research questions, more comprehensive treatment of historical and present baselines, better management of uncertainty and increasing audiences for the results are all driving the development of formal decision-analytic methods such as risk management.
c) Scenario development: researchers and stakeholders require scenarios that contain increasing

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[1] Hereafter, IPCC Working Groups I, II and III are referred to as WG I, WG II and WG III, respectively.

temporal and spatial detail, which encompass a wider range of variables and show improved internal consistency.

This chapter describes the significant developments in assessment methods since the TAR that feature in this Report. The development and application of risk management frameworks to CCIAV assessment is the major advance and is described in detail. Risk management provides a means for decision-making under uncertainty and replaces less reliable *ad hoc* methods. Progress has also been made in methods oriented towards human development and in integrated assessment. The assessment of socio-economic outcomes and adaptation options has also required the development of a range of methods to assess value including, but not restricted to, economic approaches. Each of these approaches is not mutually exclusive but overlaps with the others.

The section on characterisations of the future describes the scenarios and scenario development methods that have been constructed to provide appropriate input for these and other methods used in this Report. Many assessments have adopted scenarios based on the IPCC Special Report on Emissions Scenarios (SRES) and derivative studies. These are summarised and compared with other representations of the future. Finally, new methods of scenario construction that have yet to be tested in full CCIAV assessments are described along with data, modelling and other research needs for improving scenario resolution, integration and consistency.

2.1.1 Framing of methods used in this report

Starting as the straightforward application of climate scenarios to assess impacts and potential adaptations, CCIAV methods have expanded to manage uncertainty by addressing a variety of spatial scales, assessment directions and temporal aspects. These advances have also challenged some of the concepts and definitions associated with climate change (e.g. adaptation and vulnerability), which have had to become more inclusive to account for uses in other disciplines.

2.1.1.1 Orientation of approaches

Three major orientations can be used to describe the different structures of CCIAV assessments:
(i) The spatial scale at which the assessment takes place and linkages across scales.
(ii) The orientation taken towards its subject matter; whether a project commences with the precursors of the stress being assessed, focuses on outcomes, then diagnoses the conditions that cause those outcomes or concentrates on solutions.
(iii) The approach to characterising the future, either projecting changes forward in time or setting a target, then assessing how to reach/avoid that target (e.g. exploratory and normative approaches).

These are summarised in Table 2.1. Dessai 2003 incorporated all three of these orientations into a single structure (Figure 2.1). In this diagram, both scale and the orientation of approaches help define top-down and bottom-up methods. Top-down methods are characterised as those that downscale global scenarios to assess localised impacts and vulnerabilities at time-scales further into the future, while bottom-up methods start at the socio-economic end, concentrate on vulnerability and adaptation and deal with timescales much closer to the present. Note that the terms top-down and bottom-up are utilised variously in the literature, describing approaches to spatial scale, whether influences are exogenous (top-down) or endogenous (bottom-up), whether an assessment follows the stresses through a system or works backwards from the consequences to the stressors or whether policy is applied centrally or locally.

While it is tempting to group all of these influences into two streams, where top-down methods describe climate scenario-driven and downscaled approaches that progress through the physical sciences to socio-economic outcomes which are largely exploratory, and bottom-up approaches are those that start from the socio-economic outcomes at the local scale to manage vulnerability through adaptation and are largely normative, we note that many different combinations are possible and a number have been used in practise. For example, a normative approach at the global scale could apply a global scenario of a sustainable future, then downscale those scenarios to asses show they may be achieved at the local level. Conversely, exploratory scenarios may be developed and applied at the local scale then assessed for how they are affected by climate change. While Figure 2.1 characterises the majority of approaches that have been used to date, the number of different questions that can be posed and the physical and social contexts within which they can be framed indicate that a number of different methods is possible.

In this chapter, we group different approaches according to their underlying emphasis and direction they take to assessing climate risks: natural-hazard approach, vulnerability/resilience based approaches and policy-based approaches. These are discussed more in Section 2.2.1 as is integrated assessment.

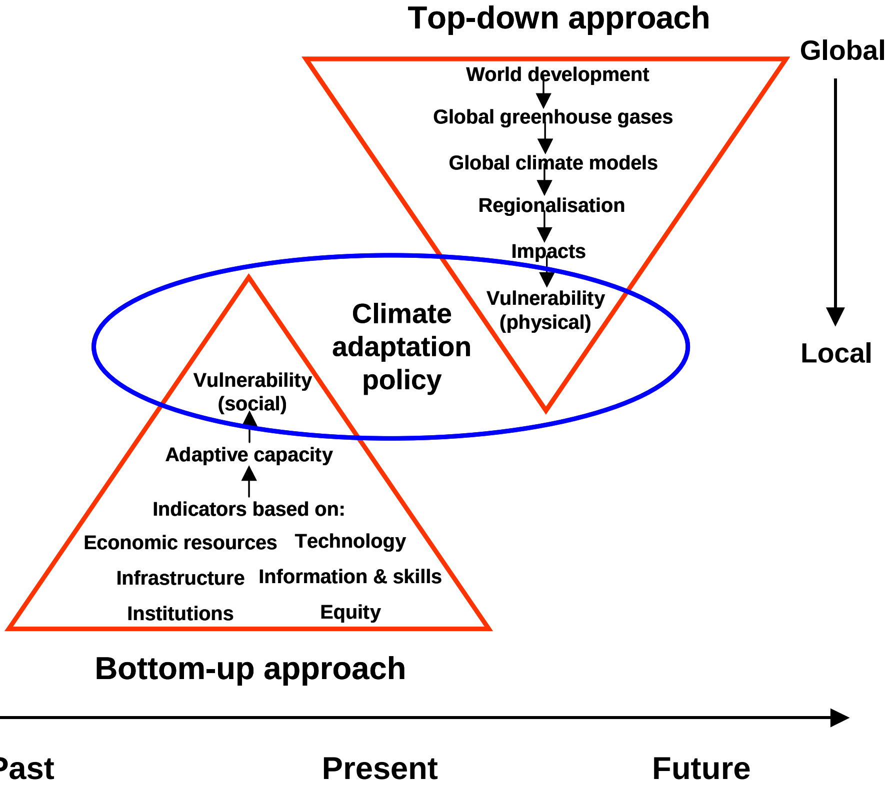


Figure 2.1: *Top-down and bottom-up approaches for addressing climate adaptation policy adapted from Dessai; Hulme 2003a.*

***Table 2.1:** Orientation of approaches to undertaking CCIAV assessments*

Orientation of approach	Description
Scale	
Top-down, global	Begins at the global scale, yields results at a regional or local scale
Bottom-up, local	Begins at the local scale, results can be aggregated to a larger scale
Subject Matter	
Scenario-driven, PSIR, (natural) hazard-driven	Begins with the precursor of change moving through to drivers, impacts and responses; Pressure, State, Impact, Response
Vulnerability-driven, critical thresholds (downside)	Assesses vulnerability (e.g. critical thresholds) then assesses likelihood of exceedance or measures to reduce vulnerability
Resilience-driven, sustainable states (upside)	Define a successful outcome or state, then establish how to achieve that under climate change
Policy-driven	Assesses an existing policy or set of actions, then determines how they fare under climate change
Time	
Projection/conditional forecast (exploratory)	Projects forward in time (transient and time slice methods)
Goal-oriented (normative)	Explores a goal then diagnoses pathways towards that goal

2.1.1.2 Definitions of key concepts

The growth of methods has challenged concepts such as adaptation, adaptive capacity and vulnerability, which in the TAR were defined in purely climate change terms. The process of bringing climate change into mainstream activities has re-introduced some of the broader definitions of some of these concepts (Downing; Patwardhan 2004). Adaptation can be described as an ongoing social process, where adaptation to climate change becomes part of a larger set of adaptive actions of which adaptation to climate change constitutes one element. This “mainstreaming” of climate change adaptation (Huq; Reid 2004) is discussed further in chapters 17 and 20. Definitions of adaptive capacity have also proved problematic, with ambiguity as to whether capacity is a realised or a potential component (Brooks 2003). In the UNDP Adaptation Policy Framework (APF), adaptive capacity is described thus: The adaptive capacity inherent in a system represents the set of resources available for adaptation, as well as the ability or capacity of that system to use these resources effectively in the pursuit of adaptation (Brooks; Adger 2004).

Vulnerability to climate change also reveals several layers when placed within a risk assessment framework depending on whether risk treatment measures have or have not been exercised. Different states of vulnerability include vulnerability to current climate, vulnerability to unmanaged climate change, where adaptation and mitigation options have not yet been exercised, and residual vulnerability, where adaptive and mitigative capacity are unlikely to be sufficient to keep an activity from harm e.g. Jones, submitted. In Chapter 19, vulnerability is defined as significant adverse affects on both natural and human systems as outlined in the United Nations Framework Assessment on Climate Change (UNFCCC), which may contribute to dangerous anthropogenic interference with the climate system.

Therefore vulnerability is highly dependent on context and scale. (Downing; Patwardhan 2004) surveyed different meanings of vulnerability in the literature, showing that broader definitions of vulnerability are most useful when addressing adaptation policy needs but counselled that when the term is used, care should be taken to clearly describe its derivation and meaning. This caution applies to the use of all such terms, where multiple derivations require that a specific context be made clear whenever on of these terms is used.

2.1.1.3 Climate change assessment and risk management frameworks

Although the enhanced greenhouse effect has been formally linked to risk management (Beer 1997: Shlyakhter; Valverde *et al*. 1995), and many climate change assessments have alluded to risk, only recently have formal links been made between climate change and risk management frameworks Jones, 2001; Beer, 2003; Willows and Connell, 2003; Lim, 2005, adaptation policy framework. Risk management approaches have been proposed for adaptation (Jones 2001: Lim; Spanger-Siegfried *et al*. 2005: Willows; Connell 2003a), mitigation (refs) and relating the two in a context suitable for addressing Article 2 of the UNFCCC (Jones; Mearns 2005: Jones; Boer 2005: Mastrandrea; Schneider 2004). Several authors have suggested that the formation of the IPCC and its successive assessments qualifies as a risk assessment of climate change. Article 2 itself is compatible with risk management. The requirement to stabilise greenhouse gases at levels sufficient to prevent dangerous anthropogenic climate change sets the criteria for assessment, while maintaining food security, facilitating sustainable economic development and allowing ecosystems to adapt naturally set the criteria for management.

Climate change assessment and risk management have many elements in common including the need to manage uncertainty, the linking of hazards and consequences, communication between technical experts and stakeholders, the mitigation of risk by reducing both the hazard and consequences of those hazards and formal processes to link all of these activities. Risk management is an iterative process, and the different stages of risk can be seen in the evolution of IPCC assessments. Three iterations of risk management can be identified through the over-riding questions being addressed through successive assessments. Each has resulted in a specific set of actions (Table 2.2).

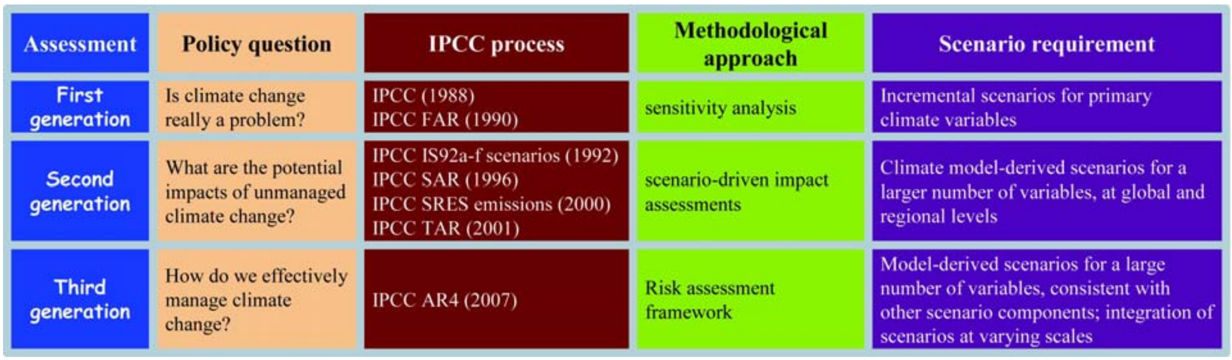
First iteration: Do greenhouse gas emissions pose a sufficient risk to warrant a significant response? This question was regarded as sufficient to commence a process which saw the formation of the IPCC 1988 and the release of its First Assessment Report (FAR) in 1990 IPCC, 1990; IPCC, 1990. The UNFCCC was drafted in response to the conclusions of the FAR (Bolin 1991) and has subsequently been ratified by 193 countries.

Second iteration: What are the risks of unmanaged climate change and what type of responses may be needed? Under the auspices of the IPCC, three sets of greenhouse gas scenarios have been developed – A, B, C and D (IPCC 1990), the IS92a–f scenarios (Pepper; Leggett *et al*. 1992) and the SRES A1, A2, B1 and B2 families (Nakicenovic; Alcamo *et al*. 2000).

Climate modelling based on those scenarios has been conducted and impacts and adaptation assessments resulting from climate scenarios derived from that information. The results feature in the Second and Third Assessment Reports of the IPCC (IPCC 1996a: 1996b: 2001a adaptation and vulnerability: 2001b). Risks are measured from the current baseline, or under future baselines projecting change (e.g. demography, land-use, technology, economy) without climate change. The resulting action has included the drafting and ratification of the Kyoto Protocol and a host of national adaptation policies.

Third iteration: How do we manage climate risks across appropriate scales, different groups and different locations? This generation of assessment sees a deeper engagement with the risk management process, where options for risk treatment are being identified, evaluated and implemented on a range of scales. This requires more than one assessment framework, whereas the first two generations were able to operate under more limited methodologies.

Table 2.2: *Evolution of risk assessments over time.*



Assessment	Policy question	IPCC process	Methodological approach	Scenario requirement
First generation	Is climate change really a problem?	IPCC (1988) IPCC FAR (1990)	sensitivity analysis	Incremental scenarios for primary climate variables
Second generation	What are the potential impacts of unmanaged climate change?	IPCC IS92a-f scenarios (1992) IPCC SAR (1996) IPCC SRES emissions (2000) IPCC TAR (2001)	scenario-driven impact assessments	Climate model-derived scenarios for a larger number of variables, at global and regional levels
Third generation	How do we effectively manage climate change?	IPCC AR4 (2007)	Risk assessment framework	Model-derived scenarios for a large number of variables, consistent with other scenario components; integration of scenarios at varying scales

The two major forms of risk treatment are the mitigation of climate change through the abatement of greenhouse gas emissions and sequestration of greenhouse gases, and adaptation to the consequences of a changing climate. Mitigation reduces the rate and magnitude of changing climate hazards associated with the enhanced greenhouse effect whereas adaptation reduces the consequences of those hazards. This relationship has important ramifications for identifying and treating climate change risks. On the one hand, adaptation and mitigation treat different parts of climate risk, so they are complementary processes in risk reduction. On the other hand, their benefits will appreciate at different time scales and in many cases adaptation and mitigation measures can be assessed and implemented separately. These aspects of complementarity and difference are dependent on context and scale, as outlined in Chapter 18.

This report describes risk management where adaptation is being used to treat climate risks or where adaptation and mitigation are both being considered. The management of climate change risks is a type of environmental risk management, which can alternatively address the damages human pose to the environment, or the damage they may experience under environmental processes (Beer 2003). Both are relevant under climate change.

2.2 New developments in methods

This section is divided into three parts: the first part describes the development and application of risk management frameworks in CCIAV assessment, the second part describes improvements to tools used to manage uncertainty and conduct assessments and the third part describes selected applications of those methods.

2.2.1 Risk management frameworks

The adaptation and application of risk management frameworks to CCIAV assessment is the most significant methodological development since the TAR. Generally, risk management is inclusive of earlier CCIAV methods (e.g. IPCC 1994), but can accommodate a wider range of approaches. It also provides a widely accepted methodology, which is also compatible with the management of non-climate risks and multiple stresses where climate change is just one factor. Here, we describe the features of risk management approaches that make it suitable for CCIAV assessment.

Risk management is defined as the culture, processes and structures that are directed towards realising potential opportunities whilst managing adverse affects (AS/NZS 2004). This definition also serves as an appropriate aim to guide adaptation to climate change-related risks. Risk itself is defined as the combination of the probability of an event and its consequences, where it is recognised that there may be more than one event, consequences can range from positive to negative and probabilities and consequences can be measured qualitatively or quantitatively (ISO 2002).

Risk management frameworks contain all of the characteristics that have also been deemed necessary for adaptation assessment. Frameworks for adaptation assessment that utilise a risk management framework have been produced by Jones 2001; Willows 2003; and Lim (2005). To illustrate this, Figure 2.2 compares the UNDP Adaptation Policy Framework and the AS/NZS (2004) risk management standard. The two frameworks have a great deal in common; including scoping, risk analysis, evaluation of treatment measures and implementation, monitoring and stakeholders involvement.

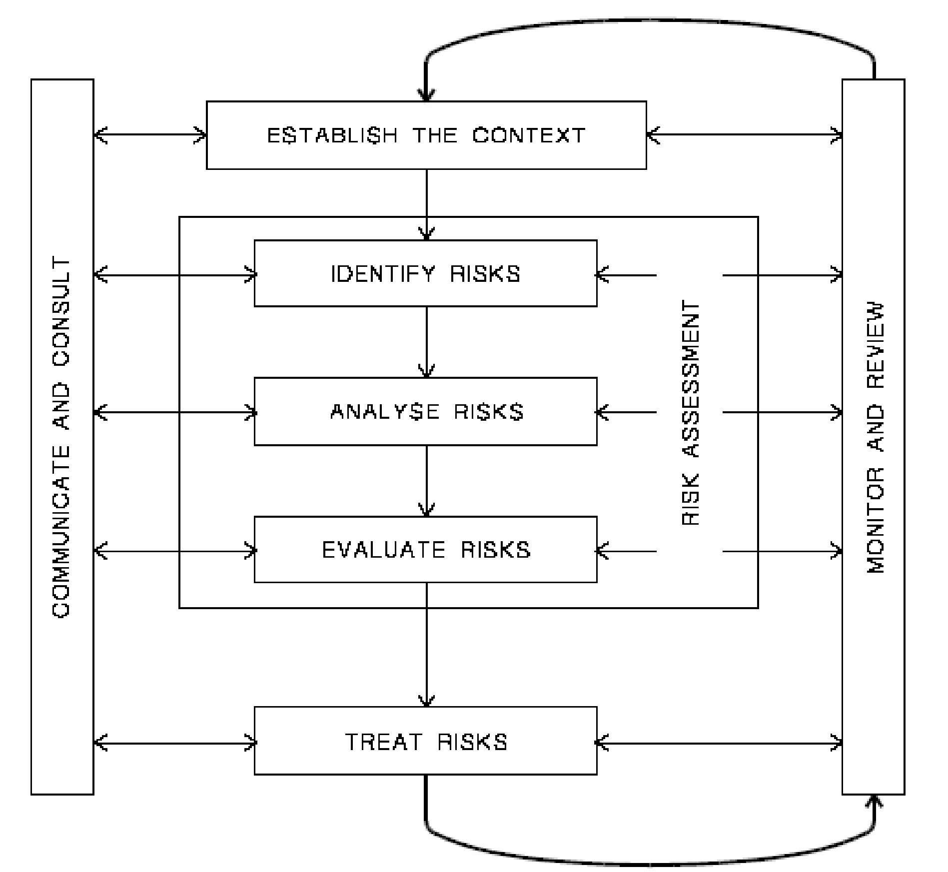
Some of the standard elements within the risk management process that can be linked to parallel CCIAV methods are:

- A scoping exercise where the context of the assessment is established. This identifies the overall method to be used.
- Risk identification. This step also identifies scenario development needs.
- Risk analysis, where the consequences and their likelihood are analysed. This is a highly developed area with a wide range of available methods to undertake impact analysis.
- Risk evaluation, where adaptation ±mitigation methods are prioritised.
- Risk treatment, where selected adaptation ±mitigation measures are applied, with follow-up monitoring and review.

Two over-arching activities are communication and consultation with stakeholders and monitoring and review, which in CCIAV assessments are largely concerned with uncertainty management and clarity and transparency surrounding the assumptions and concepts being used.

The application of risk management in the past has been hampered by the wide range of different definitions for the same terms, an issue which also affects CCIAV assessment. Recent steps to standardise risk management internationally promise to remove some of the confusion caused by different nomenclature and approaches (ISO 2002). The definitions in Box 2.1 are consistent with the methods being developed to undertake vulnerability, impacts and adaptation assessments, as described above.

(a) AS/NZS 4360:2004 risk management standard



(b) UNDP Adaptation Policy Framework

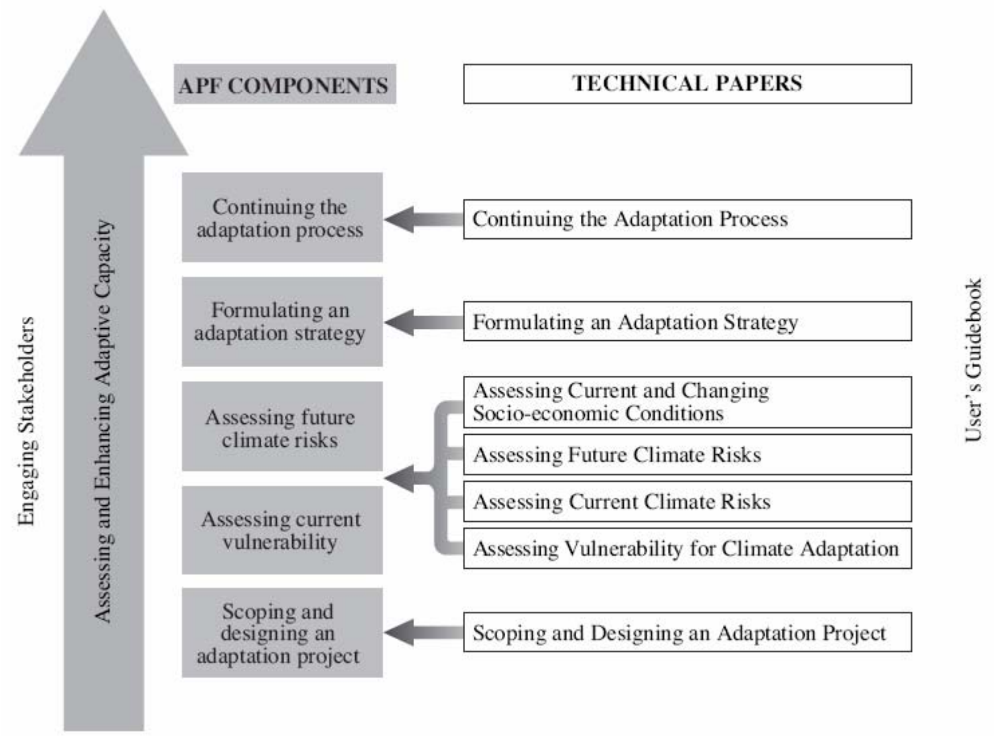


***Figure 2.2:** Comparison of (a) the AS/NZS 4360:2004 risk management standard with (b) the UNDP Adaptation Policy Framework. Note: the direction of analysis flows downwards in the former and builds upwards in the latter.*

Box 2.1: Definitions of risk and other terms

Risk management can take many different forms; therefore the terms that it utilises can have quite different meanings in various contexts. This wide use of different terms means that a single set of rigidly defined definitions is not possible. This box provides generic definitions designed so that users can extract the core meaning encompassed within each term and use it in different ways without deforming that core meaning. The definitions draw strongly from the Australian/New Zealand Standard for Risk Management, *AS/NZS 4360:2004* (AS/NZS 2004) and International Standards Organization / International Electrotechnical Commission (ISO/IEC) *Guide 73 Risk Management –Vocabulary–Guidelines.*

Consequence – the outcome or an impact of an event; consequences can be single or multiple, can range from positive to negative, can be expressed qualitatively or quantitatively and can be considered in relation to objectives.

Coping range – a range of climate variability or derived variable or set of variables with which an identifiable group, body, species or community can cope. The coping range is both a mental model and analytic tool that can be used to relate consequences to a pattern of varying climate

Exposure – duration of time subject to a harmful substance or process; exposure is not well-suited to climate risk except in comparing the propensity of a particular group, body, species or community to be harmed in relation to another.

Hazard – an event that has some likelihood of causing harm

Likelihood – a measure of probability; can be expressed qualitatively or quantitatively

Probability – the extent to which an event is likely to occur, it can be expressed as a number between zero and one. Probability can be related to a long-run relative frequency of occurrence or to a degree of belief that an event may occur (ISO 3534-2:1993)

Residual risk – the risk remaining after the implementation of risk treatment

Risk – can be broadly defined as the likelihood of an adverse event or outcome but many different specific definitions exist. These include …

Risk analysis – systematic process to understand the nature of and deduce the level of risk

Risk assessment – can be the overall process of understanding and reducing risk (e.g. Australia) or the initial part of the process of identifying and quantifying risk.

Risk criteria – terms of reference by which the significance of risk is assessed

Risk evaluation – process of comparing the level of risk against risk criteria (i.e. weighing up likelihood with consequence in order to make a decision on risk).

Risk management – the culture, processes and structures directed towards realizing potential opportunities whilst managing adverse effects (AS/NZS 4360:2004). In some jurisdictions this term is restricted to treating or controlling risk.

Risk reduction – actions to reduce the likelihood, negative consequences or both associated with a risk.

Risk sharing – the act of sharing a burden of loss or benefit of gain from a particular risk between entities.

Risk treatment – process of selection and implementation of measures to modify risk. The two major risk treatments for the enhanced greenhouse effect are adaptation and mitigation measures but treatment will require specific actions to be identified and implemented.

2.2.1.2 Identification of climate change-related risks

Risks associated with climate change take on a variety of forms. Primary climate risks include the direct effect of climate and climate-related hazards, which range in scale from small, local effects to dangerous climate change as described in the UNFCCC. Climate change impacts can also lead to secondary risks, such as those associated with land degradation or species loss, where climate change may be a partial, but not the sole, factor. Tertiary risks are twice removed such as those occurring in businesses servicing sectors affected by climate change.

Climate-related risks can be identified by characterising a particular climate hazard, or by identifying climate as a significant driver interacting with other factors. Mainstreaming is a process that integrates climate with other change factors for the purposes of management. Methods that focus directly on the assessment of adaptive capacity and specific adaptation measures will generally be based on an understanding of adaptation to current climate risks.

A further set of risks – policy-related risks – are associated with the implementation of policies or measures associated with climate change such as adaptation and mitigation. To date, such risks have generally not been explored through formal frameworks but have been assessed in an *ad hoc* manner separate to the assessment of direct and indirect climate-related risks. A growing literature on integrated assessments and climate policy is addressing these issues. A significant advantage of risk management approaches is that such issues can be explored without needing to advocate a particular view or normative outcome, beyond the broad requirement to avoid dangerous anthropogenic interference (Chapter 19).

2.2.1.2 Methods of risk management

As outlined in the introduction, a range of different orientations (describing approaches to space, subject matter and time) can be applied to risk management. Here, we classify three different templates according to their focus on the central subject matter. .Figure 2.3 shows the major elements of the CCIAV assessment process, and positions the three main analytical approaches commonly pursued: a conventional natural hazards approach, where climate scenarios are projected through impact models to assess outcomes, a vulnerability-based approach, where initial criteria such as critical thresholds are set and their levels of exceedence then assessed, and a policy-based or normative approach, where current or future policies are investigated to determine whether their aims are achieved under a changing climate (Lim; Spanger-Siegfried *et al*. 2005).

The left-hand side of the figure shows the rise in importance of the assessment of a range of historical and current factors, which progresses well beyond the construction of baseline data.

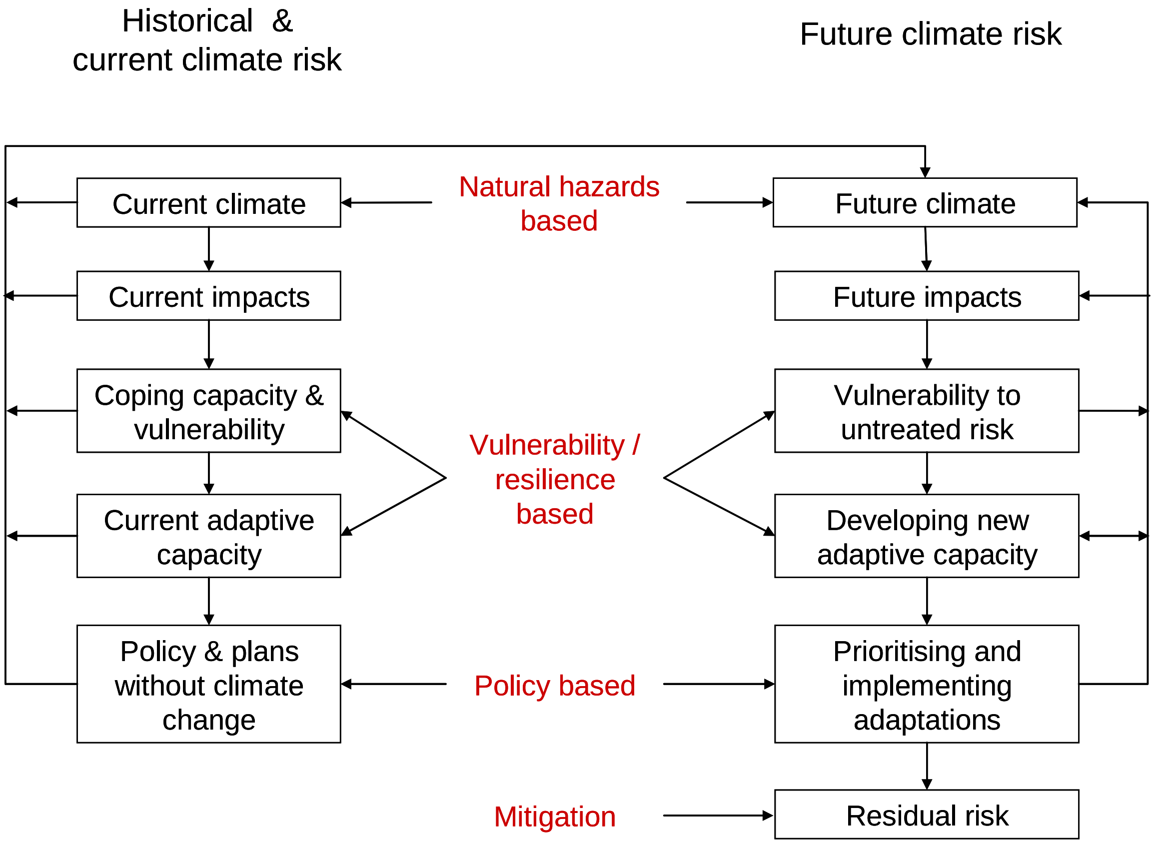


***Figure 2.3:** Flow chart showing relationship of different assessment approaches with the process of assessing current and future climate risks. Though highly simplified, the arrows aim to highlight how simple pathways through the assessment, cross-links and inverse methods are all possible, depending on the project scope and context.*

Baseline adaptation, existing adaptive capacity and adaptations to historically experienced climate risks are all utilised, especially when they have been developed to deal with climate variability and extremes, which are more difficult to simulate in climate models.

The natural hazards approach is so named after the process used in the discipline of the same name, which identifies the hazard, assesses its likelihood and impact before going on to define vulnerability. Treatment can then reduce the consequences of an event (e.g. adaptation), or modify the event itself (e.g. mitigation). Such methods are guided by coarse-scale scenarios, which may be downscaled to an appropriate resolution. This approach has its origins in the seven-step method of IPCC (1994) but has evolved to the stage where it can be used to compare past and future climate risks, to attach likelihoods to outcomes and to use integrated modelling approaches to assess large areas and/or multiple sectors (e.g. Hitz; Smith 2004).

Vulnerability and resilience-based approaches focus on socio-economic or physical outcomes to which some value has been attached, and can address either or both current and future states. Vulnerability concentrates on the downside of risk and resilience approaches focus on adaptation and adaptive capacity. Much of the assessment at the local scale is not specifically concerned with whether a particular level of change is dangerous, but instead deals with development pathways, researching the implementation of adaptation measures with different institutions and stakeholder groups. Chapters 17 (adaptation options) and 20 (climate change and sustainability) are mainly concerned with this level of operation.

Vulnerability assessed at the global scale pursues the notion of dangerous anthropogenic interference where risk approaches are applied in integrated assessments of the likelihood of exceeding dangerous levels of global warming or sea-level rise (Mastrandrea, 2004; Jones, 2005; Wigley, 2004). An extension of this is the safe corridors/tolerable windows approach (Alcamo, ??; Toth, 2003). In this approach lower and upper levels of global warming are identified, the lower levels signifying climate changes that appear to be inevitable regardless of foreseeable actions to reduce GHG emissions and hence requiring adaptation (either to exploit benefits or avoid damage), and the upper levels are maximum tolerable changes in climate beyond which unacceptable impacts would result, hence requiring mitigation. These approaches can either focus on the upside or downside of risk and take both exploratory and normative pathways.

Policy-related assessments focus on how current or proposed policies and plans may be able to cope with climate change and how they may be modified to better meet their objectives.

Table 2.3: *Summary of approaches to CCIAV assessments showing characteristics of the assessment and criteria affecting the choice of approach (based on Lim, 2005).*

Approach	Natural hazard-driven	Vulnerability/-driven	Resilience-driven	Policy-driven
Objectives	What risks may we face under this projected scenario(s)?	What is the likelihood that a specific place, process, group or activity may be harmed?	What advantages can we gain by better understanding of our current/future capacities?	How will our current plans for the future be affected by climate change?
Analytical method	Analyse possible outcomes from a given climate hazard(s) ± other drivers of change	Determine the likelihood that current or desired vulnerability may be affected by future climate hazards	Assess ability to withstand shocks, recover from setbacks and manage change.	Assess the efficacy of an existing or proposed policy under climate change
Outcomes	An understanding of current/future climate-related risks	Understanding of exposure to harm and harmful processes	Better knowledge of coping mechanisms and socio-political institutions, barriers to adaptation, increased benefits	Fitter policy under climate change
Scenario types	Exploratory scenarios of climate with other biophysical and socio-economic conditions	Characterisation of socio-economic states; can use scenarios or assess drivers through inverse methods	Baseline adaptation, adaptation analogues from history, other locations other activities	Unmanaged climate change impacts and vulnerability
Criteria influencing choice of method	• Probabilities of hazard constrained • Main drivers known • Chain of consequences understood • P(Hazard) ×	• Probabilities of hazard not constrained • Many drivers resulting in vulnerability • Multiple pathways and feedbacks	• Impacts and/or vulnerability understood • Evidence of successful adaptation • Benefits thought to be likely • Barriers to	• Policy aims sensitive to climate change • Desire to “mainstream” adaptation

	Consequences • Largely exploratory	• P(Vulnerability)/ Hazard (e.g. critical threshold exceedance) • Largely normative	adaptation recognised • Risks that require treatment	
Examples: top down bottom-up				

Several risk assessment frameworks have recently been developed that focus on adaptation (Jones 2001: Lim; Spanger-Siegfried *et al.* 2005: Willows; Connell 2003a). These frameworks are explicitly based on risk assessment methods but take a range of approaches.

Jones(2001) method was based on the seven-step method developed by the IPCC (IPCC, 1994; Parry, 1998) but added techniques for assessing critical thresholds and probabilities of exceeding those thresholds. Stakeholders are involved in risk identification, setting critical thresholds and prioritisation of adaptations. Willows (2003a) developed a risk assessment framework for the UK to assess adaptation to climate change. It is an environmental risk framework which describes a process for decision-makers to recognise and evaluate risks posed by climate change and to identify adaptive responses. The description of tools accompanying the guide draws from both risk management methods and climate impact analysis, but still requires skilled practitioners to apply them. It is now being applied in the UK and other countries. The UNDP has developed Adaptation Policy Frameworks for Climate Change (Lim; Spanger-Siegfried *et al.* 2005). The APF applies a risk assessment approach to assessing the risk of climate change, centred on human development, which is based on an initial prioritisation of current climate risks (Figure 2.2).

Moving beyond CCIAV methods, a final area of risk management is investigating the links between top-down and bottom-up approaches in order to integrate adaptation and mitigation across scales. Much of this work focuses on assessing risk as a function of mean global warming, where it is possible to aggregate a range of outcomes at a specific level of global warming in order to be able to understand the sum of local risks and thus distribute the benefits of mitigation across a range of impacts and locations (Corfee-Morlot; Höhne 2003: Jones 2003: Yohe 2004). This is a central issue of Chapter 18. Adaptation in this sense has been termed "adaptation for mitigation" (Burton; Huq *et al.* 2002). Vulnerability can be assessed at the global scale but requires aggregation of risks at all scales (Chapter 19).

2.2.1.3 Impacts, adaptation and vulnerability assessments

As implied earlier, adaptation can be assessed from several different directions, through a natural hazards approach, undertaking impact assessments driven by current and/or future climate, or by assessing vulnerability and resilience of different groups over time.

Identify and/or evaluate current adaptations

Many studies are evaluating current adaptations to climate risks in order to create and adaptation baseline from which future adaptation can be evaluated. Most of these involve stakeholder engagement:

- To identify and evaluate water harvest options/practices in coping with drought in Central Darfur (Mohamed, 2004) engaged three groups of stakeholders: policy makers and their advisers, committees and unions involved in the intervention, and relevant donors.

- In assessing agronomic adaptation measures to climate extremes in Nigeria, Adejuwon (2004) indicated that limited climate change impact studies and large uncertainties significantly constrained the reliable evaluation and development of agronomic intervention practices.
- Moswete (2004) conducted interviews to elicit perceptions from stakeholders on prospects of developing heritage tourism as a potential adaptive option to the challenges of climate change in the Greater Limpopo Basin.
- Nyong (2004) used questionnaire surveys (based on a stratified random sampling technique) and focus group discussions (a bottom-up approach) to identify adaptation options for coping with droughts among poor rural households in semi-arid Nigeria.
- Based on well-established cost-benefit principles, Louw (2004) developed an analytical framework to estimate and compare the benefits and costs of projects that reduce the expected damages from climate change. They applied the analytical framework to case studies on the Berg River Basin, South Africa; and the agriculture sector in the Gambia (Njie; Hellmuth *et al*. 2004).
- In assessing existing coping strategies in adverse environmental conditions as an analogue for adapting to climate change in rural south-western Nigeria, ??, 2004; elicited information by conducting Focus Group Discussions (FGDs); and in-depth interviews with household heads and opinion leaders. The data were processed and analyzed with the Text Base Alpha software.
- Using empirical models, Medany (2004) investigated the effectiveness of changes in agricultural practices (e.g., irrigation and sowing date) as adaptation options in the Delta region of Egypt.
- In assessing adaptation measures in the livestock sector in Mongolia, Batima (Forthcoming) used a combination of expert judgment, adaptation screening matrix, animal behaviour simulation, environmental assessment, economic analysis and adaptation decision matrix.

Assessment of resilience and adaptive capacity

Studies of resilience and adaptive capacity focus directly on risk treatment measures, with a lesser emphasis on recognising and prioritising climate risks:

- In assessing community adaptive capacity/resilience, Zakieldin (2004) adopted the sustainable livelihoods framework and its five capital stocks, i.e., natural, physical, human, social and financial. Each stock was assessed against its productivity, sustainability and equity.
- By reviewing a wide range of existing public policy and institutional frameworks, Gichangi (2004) assessed the roles of policy and institutional frameworks in vulnerability and adaptive capacity of local communities to drought in Eastern Botswana.
- Heslop-Thomas (2004) used a combination of expert interviews and a questionnaire survey backed up by secondary data to assess the capacity in Jamaica to respond to crisis in general as well as the capability to respond to the challenges posed by outbreaks of dengue fever.
- Kokot (2004) used a quantitative index, Gornitz Index to assess the vulnerability of the Uruguay coast of the Rio de la Plata. The Gornitz Index is built upon seven equally weighted variables (indicators) of coastal morphology: relief (height), geological setting, geomorphological setting, sea level rise trend, coastal retreat, tidal amplitude and wave energy.
- In assessing the adaptive capacity of an artisanal fleet exploiting fisheries off the Uruguayan coast in the estuarine front, Norbis (2004) used a wide range of indicators for the social (e.g., family, education, housing etc.), economic (e.g., fishing equipments, net income etc.), environmental (e.g., climate, winds, storm surge, eutrophication, etc.), and the legal/institutional dimensions of the livelihood of the Fleet. They also performed cost-benefit analysis to assess relevant adaptation options.
- Rawlins (2004) conducted a survey in three Caribbean island populations to investigate the

Knowledge, Attitude, and Practices (KAP) of stakeholders and communities in relation to their willingness to participate in vector source reduction strategies if the dengue fever outbreaks could be directly linked to climate variability/change.

Vulnerability assessment

There have been calls within both the CCIAV and human development literature for frameworks that are able to integrate the social and biophysical dimensions of vulnerability to climate change, and provide better quantitative methods to do so (Klein; Nicholls 1999: Polsky; Schöeter *et al.* 2003: Turner II; Kasperson *et al.* 2003). This includes the need to place vulnerability of biophysical systems within a social context, as these assessments involve value judgements about the identification of important ecosystem services and of the acceptability or otherwise of ecosystem change e.g. Neudoerffer, submitted; de Chazal, in prep. There is also a recognised need to make progress in the development of quantitative, spatially explicit methods for vulnerability assessment (Metzger; Schöeter submitted).

Two recent projects assessing ecosystem vulnerability by downscaling global scenarios to a regional level are the ATEAM project (Advanced Terrestrial Ecosystem Analysis and Modelling[2]) and the VISTA project (Vulnerability of ecosystem services to land use change in traditional agricultural landscapes[3]). Both projects make use of the SRES scenarios (see section 2.3.3) to assess changes in ecosystem services over the next 50 to100 years as a response to the combined effects of climate change, land-use change, and atmospheric pollution. Both projects involve stakeholder participation to assess vulnerability.

The ATEAM project analysed pan-European ecosystem vulnerability to global change via simulation, using multiple, internally consistent scenarios of climate and land use change, a range of ecosystem models and a generic adaptive capacity index, placing the results in a vulnerability framework constructed with stakeholder participation (Schroeder 2005). The study found that ecosystem service provision in Europe is sensitive to large changes in both climate and land use. Some changes might be considered positive (e.g. increased forest productivity), some present possible opportunities (e.g. "surplus" agricultural land available for biomass energy production), but most changes increase vulnerability (e.g. declining soil fertility, increase risk of forest fires, biodiversity losses especially in the Mediterranean and mountain regions.

The VISTA project using 11 study sites across Europe's mountain, Mediterranean, cold and otherwise marginally productive regions. Vulnerability assessment is framed in the context of social judgements about the acceptability or otherwise of changes in ecosystem services. Social surveys with selected stakeholders are used to identify and value ecosystem services. Five matrices, representing either social information, ecological information or a combination quantify, link and integrate social and biophysical information. The conceptual and methodological framework accommodates a full range of stakeholders and ecosystem services, where both can be classified, grouped and weighted as appropriate, enabling a wide range of vulnerability assessments be performed, at a range of different regions (de Chazal, in prep.).

Recent bottom-up vulnerability assessments include:

- Eakin (2004) conducted an array of activities (e.g., debriefing sessions, survey, in-depth interview, group discussions etc.) to engage stakeholders in the process of defining factors contributing to social vulnerability and affecting adaptive capacities of in selected farmer

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[2] http://www.pik-potsdam.de/ateam

[3] http://lotus5.vitamib.com/hnb/vista/vista.nsf/Web/Frame?openform

groups in Argentina and Mexico.
- To assess vulnerability of farmer communities in Mexico, Wehbe (2004) applied a multi-criteria model to determine sensitivity and adaptive capacity indices through a Analytical Hierarchy Process (AHP). Sensitivity and adaptive capacity indices were then aggregated through fuzzy logic to obtain vulnerability index.
- Pulhin (2004) modified and applied a set of participatory rural appraisal techniques (e.g., time line analysis, participatory impact assessment, participatory mapping of vulnerable groups and places) to elicit view from the watershed communities on vulnerable people and places to climate variability and extremes in the Philippines.
- Batima(Forthcoming) used a combination of indexing, coping range, and vulnerability mapping techniques to assessment the vulnerability of Mongolian livestock sector to climate variability and changes.
- Multi-criteria technique was applied by Chinvanno *et al.* to assess the vulnerability of rain-fed rice producers to climate variability and change in the Meking River Delta region (Chinvanno, forthcoming).

2.2.1.4 Integrated methods

Integration requires the combination of different elements in an assessment system that represents complex interactions across spatial and temporal scales, processes and activities, with the assessment itself requiring the integration of research disciplines. Integration is often referred to as "vertical", when describing process and "horizontal" when describing breadth across scale or activities. Integrated assessments may involve one or more mathematical models, which may themselves be integrated. Integrated models range from simple models linking large-scale processes, through models of intermediate complexity to complex, physically explicit representation of Earth systems. These different levels involve a trade-off between realism and flexibility, where simple models are better at representing uncertainty, whereas scenarios and projections from complex models will be more precise if not more accurate. Complex models also generally produce a greater range of output.

Schellnhuber (2004) offer two rationales for integration: 1) the systematic investigation of damages in a holistic manner, and 2) a theory-based approach to defining dangerous climate change which includes an analysis of the benefits of climate policy in avoiding such a state. Particularly in regard to the second point, there is broad agreement that no single theory describes and explains dynamic behaviour across scales in socio-economic and ecological systems (Rotmans; Rothman 2003), and that a single monolithic model cannot be used to assemble all required components in a single entity, or provide responses to questions in a rapid turn around time (Schellnhuber; Warren *et al.* 2004). For that reason, modular assemblages of different simulation elements (e.g. Warren 2002) are being constructed to conduct participatory modelling with stakeholders (van Asselt Marjolein; Rijkens-Komp 2002).

Cross-sectoral integration

Integration across sectors is required for a large number of purposes such as national assessments, an understanding of economic and trade effects, joint population and climate studies and so on. National assessments, such as the US National Assessment, can utilise nationally integrated models (e.g. Hurd; Callaway *et al.* 2004: Izaurralde; Rosenberg *et al.* 2003: Rosenberg; Brown *et al.* 2003), or can synthesise a number of disparate studies for policy makers (e.g. West; Gawith 2005). Markets and trade also can have significant effects. For example, a study assessing the global impacts of climate change and trade on forests and forest products have implications for the ability to stabilise carbon dioxide in the atmosphere. They can also significantly affect regional welfare, negatively affecting those regions with high production costs (Perez-Garcia; Joyce *et al.* 2002)

Integrated models of simple to intermediate complexity are increasingly being adapted to undertake risk assessment through probabilistic analysis. These are discussed in Section 2.2.3.

Integration of climate with other stressors and processes
One of the main benefits of integration is that it produces results that cannot be produced in isolation. For example, the Millennium Ecosystem Assessment was designed to assess the impact of a broad range of stresses on ecosystem services, of which climate change was only one. The MA assessed conditions and trends, developed scenarios and assessed response options. It is releasing its finding in a series of reports and is providing the methods and tools for regional groups to carry out their own integrated assessments.

Both impacts and vulnerability assessments can also benefits from taking the multiple stressors approach. For example, the AIR-CLIM Project integrated climate and air pollution impacts covering Europe between 1995 and 2100. Scenarios consisted of trends in emissions, acid deposition, nitrogen deposition and climate change. Critical loads and critical levels were used to assess the impacts of climate change and pollution on forest ecosystems. The conclusions were that while the physical impacts were weakly coupled, in the policy environment air pollution were strongly coupled, and the indirect effects of climate policies were found to reduce the costs of controlling air pollution emissions by more than 50% (Alcamo; Mayerhofer *et al*. 2002).

A study carried out in India by O'Brien *et al*. investigated regional vulnerability to climate change in combination with other global stressors (O'Brien, 2004). They used both vulnerability mapping and local-level case studies to assess regions that were "double exposed" to both climate change and globalisation trends. Thus, differential vulnerability can be used to identify the need for policy interventions.

Coupling of impacts, adaptation and vulnerability assessments with Earth System Models
Earth System Models of intermediate complexity that link the atmosphere, oceans, cryosphere, land system and biosphere are being developed to assess a range of geobiological processes which are reported in WGI, but are also being used to assess impacts, particularly global scale singular events that may be considered dangerous (see chapter 19). *[To be expanded for the SOD]*

2.2.2 New and improved methods for measuring and interpreting CCIAV

2.2.2.1 Data needs for assessment

As the range and complexity of different methods increases, so to do the data requirements for those assessments. Two main drivers for data of increasing complexity are the wish to explicitly represent climate variability and extremes in impact assessments and the need to integrate current biophysical and socio-economic data to understand current climate risks before assessing how those risks may change in the future. In turn, this requires scenarios of increasing resolution encompassing biophysical to socio-economic characterisations of future conditions, discussed in detail in Section 2-3.

In addition to the existing traditional sources of data, many assessments are now obtaining data through stakeholder elicitation and survey methods. For example, in many traditional societies a large number of social interactions may not be recorded by bureaucratic processes, but records of how societies adapt to climate change, how they perceive risk and measure their vulnerability exist with community members. Even in data rich situations it is likely that some additional data from stakeholders will be required.

An overview of data needs and scenario development for top-down and bottom-up approaches to CCIAV, is summarised in the following:

Top-down approach. For assessments conducted at global and sub-continental scale, it may be quite appropriate to apply socio-economic projections produced by international agencies such as the United Nations and World Bank. The SRES and IS92 scenarios are two such examples. Some large-scale scenarios are aggregated from projections at national scale, providing some scope to conduct analysis at national scale, even if the results are expressed in aggregate form. This "top-down" approach has been pursued in several recent global studies of water resources (e.g., Alcamo, 1997; Arnell, 1999; Arnell, 2004, global water resources; Arnell, 2001, hydrology and water resources; Vörösmarty, 2000), ecosystems (e.g. Levy; Cannell *et al*. 2004: e.g. White; Cannell *et al*. 1999), food security (e.g. Parry, 1999; Parry, 2004; Fischer, 2002), coastal impacts (e.g. Nicholls, 1999; Nicholls, 2004, coastal flooding}, human health (Martens; Kovats *et al*. 1999: van Lieshout; Kovats *et al*. 2004), and environmental risks in general (e.g. Alcamo, 2001; Parry, 2001). A number of such studies are summarised by (Hitz; Smith 2004).

Bottom-up approach. Many impact and adaptation studies have an exclusively local focus, or require geographically explicit data before aggregating results to national or regional scale. For such studies, it is often inappropriate to attempt to use simple downscaling approaches to obtain local estimates from global projections such as the SRES and IS92 scenarios. For example, population trends at national scale may be upward, but this may mask important trends in migration from rural to urban areas. Nationally-averaged scenarios of per capita income or wealth may distort large disparities in the ratio between rich and poor. To obtain credible scenarios at the local and regional scale, historical data and information about ongoing trends are of great importance (Lim; Spanger-Siegfried *et al*. 2005: Malone; La Rovere 2004). While some reference to national estimates downscaled from global scenarios (i.e., the "top-down" approach) may provide a framework for scenario development, the plausibility and credibility of scenarios will ultimately be judged by experts at local scale (e.g. Berkhout; Hertin *et al*. 2002). This "bottom-up" approach to scenario development requires access to local knowledge and data (Lorenzoni, 2000). Many of the impact studies assessed in the AR4 have followed this approach to scenario development.

2.2.2.2 Thresholds and criteria for risk

The clearest distinction between risk management and the straightforward prediction of outcomes is in the development of criteria which set the terms of reference by which the significance of risk is assessed. This allows risk to be evaluated and treatment actions to be tested, prioritised and implemented. In CCIAV, this requires linking impacts to potential outcomes and is a large driver behind vulnerability and resilience-based approaches, where the focus is on outcomes and risk treatment, rather than the stress and resulting hazard.

In climate change assessment, this has involved the use of thresholds; in particular critical thresholds. The simplest definition of a threshold is a non-linear response of a variable, activity or system to an internal or external stress. Thresholds are used in assessing change in two ways:

1. A threshold that represent a change in state, where a systems shifts from one identifiable set of

conditions to another.

2. A criterion denoting a change in condition that invites some form of response. A critical threshold is a change where the degree of harm exceeds a given level of tolerance (IPCC 1994: Parry; Carter *et al*. 1996: Pittock; Jones 2000).

In the first sense, thresholds are a property of simple through to complex systems representing a step-wise or non-linear change. Geophysical and biophysical thresholds represent a distinct change in conditions, such as the drying of a wetland, floods or budburst. Climatic thresholds include frost, snow and monsoon onset. Ecological thresholds include breeding events, local to global extinction or the removal of specific conditions for survival. In a complex system, a change in state usually denotes a new set of conditions where a return to the original set of conditions is either impossible, or involves a larger response than that which led to the state change in the first place. This type of threshold tends to be value neutral.

In the second sense, thresholds are a value-laden, or normative, concept, where crossing a boundary "means something" in terms of the response. Such a threshold may be a clear biophysical change as above, but a value judgement is also attached to the result. A threshold can be attached to a linear, gradational scale, the response being the non-linear aspect; for example, so called management thresholds (Kenny; Warrick *et al*. 2000), where a linear biophysical scale is linked to a less explicit non-linear response. For example, extreme heat may be registered at 30°C in some places, 35°C in others and even 40°C and 45°C in some locations, depending on responses conditioned by past experience.

Exceeding a management or normative threshold will result in a change of legal, regulatory, economic or cultural behaviour. This is especially so in the use of the concept of the critical threshold, where criticality exceeds a given level of tolerance, so tolerance is set subjectively on the basis of a value system. These are used in defining the coping range (next section).

A number of studies have described methods for deriving thresholds with stakeholders, thus avoiding the pitfall of researchers ascribing their own values to the assessment (Conde; Lonsdale 2004: Kenny; Warrick *et al*. 2000: Pittock; Jones 2000) describe a range of methods for eliciting information from stakeholders that can be used in the setting of thresholds. Stakeholders become responsible for the management of the uncertainties associated with that threshold. The identification of impact thresholds in the early stage of an assessment will sharpen the aims of the assessment and aid in the communication of the results (Jones 2001).

2.2.2.3 Defining coping ranges

The coping range of climate (Hewitt; Burton 1971) is described in the TAR as the capacity of systems to accommodate variations in climatic conditions (Smith; H.-J *et al*. 2001) so serves as a suitable template for understanding the relationship between changing climate hazards and society. The concept of the coping range has since been expanded to incorporate concepts of current and future adaptation, planning and policy horizons, and likelihood (Yohe, 2002; Willows, 2003; Lim, 2005; Jones, submitted). It can thus serve as a conceptual model (Morgan; Fischhoff *et al*. 2001) which can be used to integrate analytical techniques with a broader understanding of climate-society relationships (Jones; Mearns 2005).

The coping range is used to link the understanding of current adaptation to climate with potential needs for adaptation under climate change. It is a useful mental model to use with stakeholders who often have an intuitive understanding of which risks can be coped with, which cannot and what the consequences may be that can be developed into an quantitative model (Jones, 2004). It is constructed of one or more climate or climate-related variables upon which socio-economic responses are mapped. The core of the coping range contains beneficial outcomes. Towards one or both edges of the coping range outcomes become negative but tolerable. Beyond the coping range, the damages or losses are no longer tolerable and denote a vulnerable state. The coping range is separated from areas of vulnerability by one or more critical thresholds (Pittock; Jones 2000). A coping range is usually specific to an activity, group and/or sector, though society-wide coping ranges have been proposed (Yohe; Tol 2002).

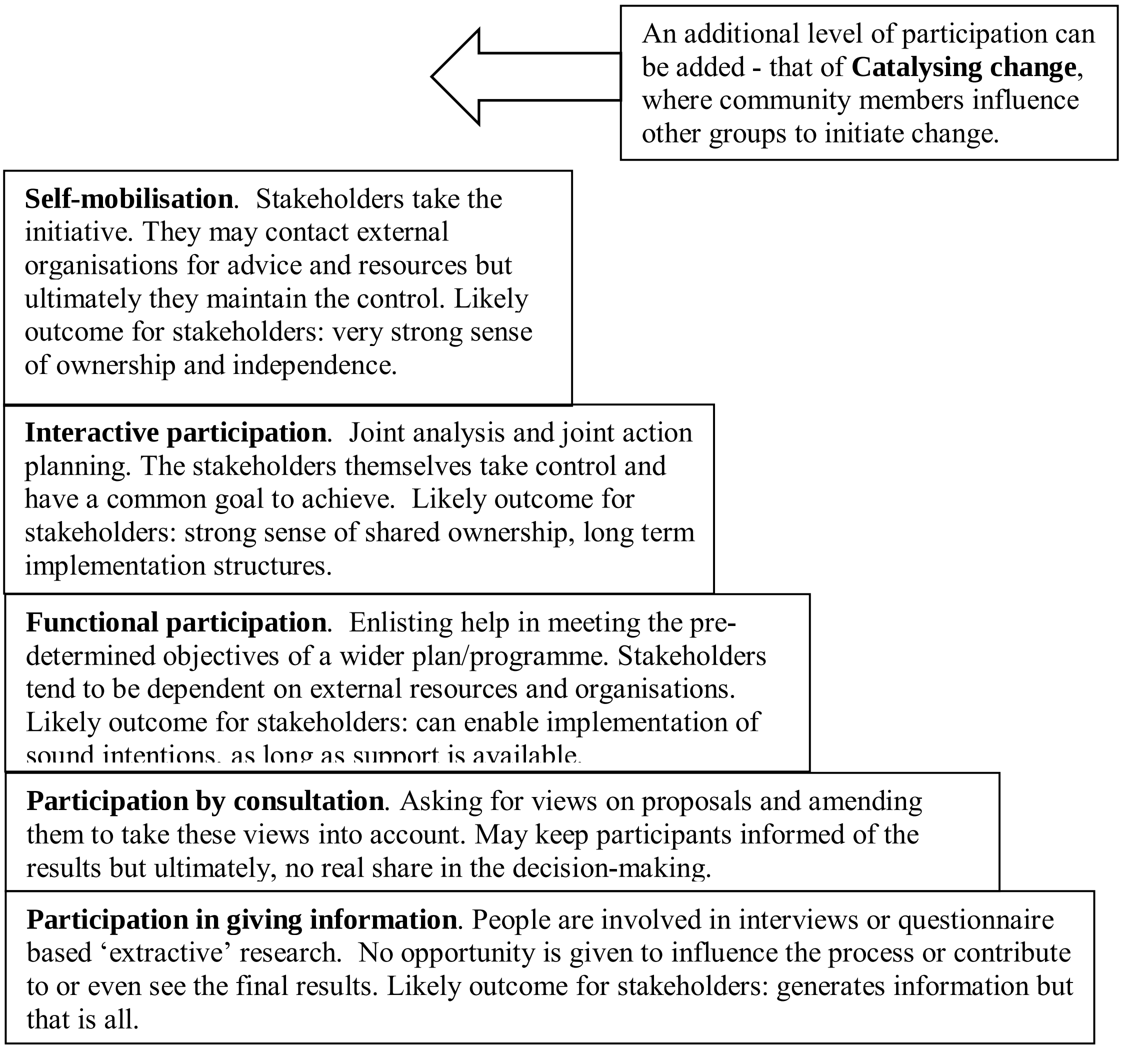
Risk is assessed by calculating how often the coping range is exceeded under given conditions. For example, (Jones; Page 2001) constructed two separate critical thresholds for the Macquarie River catchment in Australia irrigation allocation and environmental flows. They found that the probability of exceeding these thresholds was a function of both natural climate variability and climate change. (Yohe; Tol 2002) explored hypothetical upper and lower critical thresholds for the Nile River using current and historical streamflow data. The upper threshold denoted serious flooding, and the lower threshold the minimum flow required to supply water demand. Historical frequency of exceedence served as a baseline from which to measure changing risks using a range of climate scenarios.

2.2.2.4 Stakeholder involvement

Stakeholders are individuals or groups who have anything of value that may be affected by climate change or by the actions taken to manage the ensuing risks of climate. People's knowledge and expertise comprise the principle resource for adapting to the impacts of climate change. Adaptive capacity is developed if people have time to strengthen networks, knowledge, resources and the willingness to find solutions. Through an ongoing process of negotiation and modification stakeholders can assess the viability of adaptive measures, as they are able to integrate the social, economic and cultural context in order to perform that evaluation. The research community and the stakeholders can incorporate the scientific or factual information with the local knowledge and experience of change and responses over time to develop adaptive strategies (Conde; Lonsdale 2004).

Approaches to stakeholder engagement vary from quite passive interactions, where the stakeholders provide information, to 'self mobilisation', where the stakeholders themselves initiate and design the process. Different levels of stakeholder engagement are shown in Figure 2.4. Stakeholders are seen as crucial in assessing the needs for developing policies and measures to adapt to climate change, because they are those who will be most affected and need to carry out adaptation (Burton, 2002; Lim, 2004). These needs have been recognised in regional and national approaches to assessing climate impacts and adaptation, including within the UK Climate Impacts Programme (UKCIP – (McKenzie Hedger; Gawith *et al*. 2000), the US National Assessment (Corell; *et al*. 2003: Joyce 2003: National-Assessment-Team 2000), the Arctic Climate Impact Assessment (ACIA 2004), the Finnish National Climate Change Adaptation Strategy (Marttila; Granholm *et al*. 2005) and related FINADAPT research consortium (Carter; Kankaanpää 2003: 2004), and the Mackenzie Basin Impact Study (Cohen 1997).

A growing literature is investigating the role of stakeholders in developing and understanding adaptive capacity. It is generally being recognised that general determinants of community capacity to manage current climate risks relate to upper tier political and institutional arrangements; the character of, and relationships between, agencies, groups, and individuals involved in water management; and the adequacy of financial, human, information, and technical resources. However, although many of these institutional factors are generic their local expressions are geographically specific (Cebon; *et al.* 1999: Cohen 1997: Ivey; *et al.* 2004).



An additional level of participation can be added - that of **Catalysing change**, where community members influence other groups to initiate change.

Self-mobilisation. Stakeholders take the initiative. They may contact external organisations for advice and resources but ultimately they maintain the control. Likely outcome for stakeholders: very strong sense of ownership and independence.

Interactive participation. Joint analysis and joint action planning. The stakeholders themselves take control and have a common goal to achieve. Likely outcome for stakeholders: strong sense of shared ownership, long term implementation structures.

Functional participation. Enlisting help in meeting the pre-determined objectives of a wider plan/programme. Stakeholders tend to be dependent on external resources and organisations. Likely outcome for stakeholders: can enable implementation of sound intentions, as long as support is available.

Participation by consultation. Asking for views on proposals and amending them to take these views into account. May keep participants informed of the results but ultimately, no real share in the decision-making.

Participation in giving information. People are involved in interviews or questionnaire based ‘extractive’ research. No opportunity is given to influence the process or contribute to or even see the final results. Likely outcome for stakeholders: generates information but that is all.

Figure 2.4: *Ladder of stakeholder participation (based on Pretty 1994, Conde & Lonsdale 2004)*

Assessing the understanding and perception of risk amongst stakeholders is also useful for understanding how information can be exchanged and the level of information needed in addition their receptiveness to particular adaptation options e.g. Behringer, 2000; Lorenzoni, 2000; Shackley, 2003. Similar approaches have been used to assess scenario needs (Bärlund; Carter 2002). The VISTA project is using interviews and questionnaires with selected stakeholders to judge the acceptability or otherwise of prospective changes in ecosystem services in agro-pastoral landscapes in Europe under four of the IPCC SRES scenarios for the 2050 timeline (de Chazal, in prep.). Stakeholders are also becoming more involved in participatory modelling approaches (e.g. (Marjolein; Rijkens-Klomp 2002: Welp 2001). Stakeholders are also taking a lead in projects designed to promote awareness of the importance of adaptation, for instance in the ESPACE project for adapting to climate events in spatial planning in western Europe (Nadarajah; Rankin 2005)

2.2.2.5 Prioritising adaptation measures

Evaluating specific adaptation options will benefit from the use of formal methods for selection and prioritisation (Niang-Diop; Bosch 2004). Formal methods are most easily applied to sectoral and multi-sectoral adaptation measures and project-scale interventions. Often for cross-sectoral measures such as institutional reform, legislation, etc. the benefits or impacts of a measure cannot be quantified, therefore subjective ways to determine the attractiveness of these measures will have to be followed.

Niang-Diop(2004) discuss the following four main methods, indicating in which cases what method is most suitable for selection/prioritisation:

- Cost Benefit Analysis (CBA): comparing costs and benefits of a measure with a view to deciding whether it is attractive to undertake an activity (a project or a project-type adaptation measure)
- Multi-criteria Analysis (MCA): assesses between three and eight criteria, sometimes with different weightings, orders and other methods of uncertainty analysis
- Cost Effectiveness Analysis (CEA): Some where between CBA and MCA, it evaluates different options that achieve the same objective, and compares those to determine how a well-defined objective can be met with least cost.
- Expert judgement: structured methods of eliciting information from experts who may well be stakeholders who utilise their experience to make expert judgement

Of the four methods, cost-benefit analysis can best handle optimisation and prioritisation, providing an absolute measure of desirability, but is judged by only the one criterion of economic efficiency. It is also heavy on data requirements. Multi-criteria analysis is useful where several criteria are seen as important. Multi-criteria analysis is normally used for the ranking of alternative options, but – if the do-nothing case is included as an alternative – it can also answer the question whether a specific measure is better than tolerating the risk. Subjective judgement plays an important role in this method, making outcomes more arbitrary than that of cost-benefit analysis. Cost-effectiveness analysis is a method somewhat in between cost-benefit analysis and multi-criteria analysis. However, as is the case with multi-criteria analysis, cost-effective analysis only produces a ranking.

Expert judgement includes the use of both technical and stakeholder expertise in prioritisation. In the case of stakeholder expertise, they can rank outcomes based on the experience of past adaptations, or prioritise the outcomes of more formal methods such as those listed above. Other methods currently in use include planning and regulatory approaches, environmental impact assessment, and triple bottom line assessment, which may use several of the above approaches.

The Compendium of Decision Tools lists more methods than dealt with here, including sector-specific tools (UNFCCC 2004) and also the Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies (Feenstra; Burton *et al.* 1998) discusses the selection issue and goes into detail by sector.

The financing of adaptation has received some attention. Bouwer (2005) suggest applying a more structured decision-making framework to decisions affecting disaster management and adaptation to climate change, involving risk sharing between private and publicly borne risks. Quiggin (2003) argue that most of the costs of climate change will be adjustment costs, or the costs of adaptation, which depend on the rate of change and commensurate extremes of climate variability. By treating the result of an analysis as an optimal results and not factoring in such adjustments, the above methods will under-estimate the true costs.

2.2.2.6 Assessing policy benefits

The assessment of climate policy benefits has arisen out of the need to assess the complementary but different benefits of adaptation and mitigation and balance these against the risks associated with various policy options. The relationship between climate-related and policy-related risks has largely been overlooked with the result that much of the policy and analytical discourse has been characterized by asymmetric attention to the costs of mitigation commitments on the one hand, and, more recently, the potential benefits of adaptation on the other (Corfee-Morlot, 2004). Analysis of the benefits of mitigation has been dominated by attention to near-term secondary or ancillary benefits rather than the benefits of avoided damage (Corfee-Morlot, 2004). There is also only very limited analysis of the costs of adaptation.

The benefits of avoided damage can be assessed in a risk assessment framework, providing a means to assess the trade offs associated with decisions about mitigation (O'Neill, 2002; Arnell, 2002; Jacoby, 2003). This requires impact analyses to be carried out for a range of scenarios with unmanaged greenhouse gas emissions to be contrasted with scenarios where some type of management has been imposed *[GEC references]*.

O'Neill 2002 recently traced the development of global benchmarks for key impacts of climate change associated with two types of concerns outlined above—irreversible change and the risk of surprise, non-linear events. Their work suggests that benchmarks indicators could guide policy decisions, exploring three distinct indicators of risk – extinction of coral reef systems, the breakdown of the THC, and disintegration of the WAIS – including the setting of clear thresholds where the risk of abrupt and irreversible change is high. The aggregration of local and regional thresholds will also help to identify thresholds for global mean temperature change or rates of change that limit the risk of irreversible damage to vital natural or human systems (Jones, 2003). In turn, such thresholds provide a means to establish boundaries for near-term actions consistent with emission pathways that lead to stabilisation of greenhouse gas concentrations.

It has also been shown, that in terms of exceeding successively higher levels of global warming and sea level rise, that the likelihood of exceeding lower levels is much higher than for higher levels and that this can be carried out within a probabilistic framework (Jones, 2003; Jones, 2004; Mastrandrea, 2004; Yohe, 2004). However, although this may be achieved for key global vulnerabilities there is no straightforward way to integrate local critical thresholds because of the variety of ways in which they may be measured (Jacoby, 2004). Integrated assessment models may do so, but it is difficult to run them within a probabilistic framework, although using an integrated model of moderate complexity (Webster; Forest *et al*. 2003) link selected critical outcomes to different levels of forcing under both SRES and stabilisation scenarios.

2.2.3 Managing and communicating uncertainty

Managing and communicating uncertainty is crucial to the success of impacts, adaptation studies, risk assessments in general, and any type of decision making associated with climate change. In the next three sections we review major aspects of the quantitative language of uncertainty, outline key issues in communicating uncertainty, and finally present the current state of knowledge on managing uncertainty. While this uncertainty can apply to many different aspects of the climate change problem (e.g., uncertainties in regional climate change, uncertainties in the impacts) the main focus here is on managing the uncertainty in the climate change itself.

2.2.3.1 Probabilities and Bayesian Analysis

Probability is the best known and most widely used calculus for quantifying uncertainty and is often referred to as the "language of uncertainty". Since the TAR, a great deal of research has attempted to quantify the uncertainties in climate change research using probabilities of varying kinds. While developing probability density functions (PDFs) or cumulative distribution functions (CDFs) has become a common activity in climate change research, all P/CDFs are not derived in the same way, nor do they always really represent the "same" type of quantification. PDFs are usually derived in one of two ways, using the frequentist approach or the Bayesian (subjective) approach. In the simplest application of a frequentist approach, observed data are used to derive, for example, a distribution of daily temperatures over a series of years at one location, by analyzing the frequencies of the data and then often fitting the data to a known distribution. Similarly, one can easily describe probabilistically the frequency of repetitive events in the past from data (e.g., likelihood of daily maximum temperature in July exceeding 35°C or the likelihood of a certain flood level in a river system being exceeded in any given year). When addressing future climate this simple approach cannot be straightforwardly applied. Probabilistic models have to account for drifts and trends when using observations to infer future projections, and/or need to address the relation between GCM output and real climate when incorporating data from simulations. Both frequentist and Bayesian methods can be used for these kinds of analysis. But when it comes to the probabilistic description of single events both past and future, (e.g. global mean temperature at the end of the 20th and 21st century) a Bayesian approach has a natural advantage, since it defines probability as "degree of belief" rather than as the limit of an observed frequency (Savage 1954).

The general term "Bayesian approach" is related to but not identical with Bayesian statistical modelling, which is often used in developing probabilities about the future (e.g., Tebaldi, 2004). It is derived from the work of Thomas Bayes in the mid eighteenth century ('Essay towards solving a problem in the doctrine of chances,' 1763). In a Bayesian statistical model the existing knowledge (before collecting the data) about the uncertain quantity of interest (e.g. Future mean climate change in 2100) is formalized as a PDF, the prior distribution. The data collected provide information about the uncertain quantity that is incorporated in the prior via Bayes' Theorem, resulting in a new, reshaped PDF, the posterior distribution. The posterior may be considered the final probability that one is interested in determining since it incorporates the information acquired through prior beliefs (expert knowledge, prior studies or subjective opinions) and updated by the data, whose plausibility reshapes our degree of belief in the quantity of interest (Berry 1996). It is in the formulation of the priors that subjective choice commonly resides; however, in any Bayesian model, clear justifications for the choice of priors need to be articulated. Incorporating experts' points of view is a way of anchoring the analysis in shared scientific understanding of the relevant uncertainties. For example, (Morgan; Keith 1995) used an expert judgment approach to elicit opinions from climate scientists regarding climate sensitivity.

Subjective assessments of uncertainty are affected by cognitive heuristics, or simple unconscious rules people use to make judgements. It is well known that cognitive heuristics can lead to biases that result in misjudgements about uncertainty. The most well known are "availability", "anchoring", and "representativeness". The anchoring phenomenon refers to the over-reliance on a reference or starting point. Representativeness concerns the tendency of people to judge an object's likelihood of being a member in a class based on how much the object resembles their perception of that class. Availability heuristic refers to the ease with which one can remember similar cases. More on this topic is covered in section 2.2.3.2.

The way in which uncertainty is handled in the IPCC AR4 very much assumes a Bayesian approach, wherein the expert opinion of the chapter authors is used to formulate verbal descriptions of uncertainty, which correspond to probability ranges (see document on Uncertainty in introductory chapter of this volume).

2.2.3.2 Communicating Uncertainty and Risk

A growing number of studies have shown the communication of uncertainty to be important to help people respond to climate change (Moss, 2004). However, empirical research has highlighted difficulties people have making consistent decisions when they need to take uncertainty and probability into account (Zeckhauser, 1996). People often rely on intuitive decision-making processes, or heuristics, in solving complicated problems of judgment and decision-making (Tversky; Kahneman 1974). In many cases these heuristics are surprisingly successful at leading to successful decisions in the context of information and time constraints (Gigerenzer 2000: Muramatsu; Hanich 2005). In other cases, however, heuristics can lead to predictable inconsistencies or errors of judgment. For example, people consistently overestimate the likelihood of low probability events (Kahneman; Tversky 1979: Kammen; Shlyakter *et al*. 1994), or events that have a strong emotional impact (Elster 1998: Tversky; Kahneman 1973), and as a result often choices that increase, rather than decrease, their exposure to harm (Thaler; Johnson 1990). These patterns of decision-making, and some of the resulting problems, appear not just in lay people, but also in experts and professionals, especially when these professional are operating outside their immediate field of expertise (Gordon 1996).

The methods for communicating risk and uncertainty—as practiced by agencies with a mandate to improve environmental, health, and workplace safety—have evolved over the last thirty years in response to such findings (Leiss 1996). An early approach was to avoid communicating probability and uncertainty, so that people would not be confused, and instead communicate the most likely outcome, or the recommended course of action, in order to convince people to make an appropriate choice (Zeckhauser; Viscusi 1990). More recently, risk communication practitioners have recognized that this can lead to a loss of credibility, especially when the most likely event does not actually occur, and hence the prediction appears wrong (Podestá; *et al* 2002). It can also lead to conflict between experts and stakeholders, when experts' recommendations seem dangerous to decision-makers, or when experts make mistaken assumptions about the stakeholders' goals (Hoffman-Reim; Wynne 2002). What most risk researchers now consider the ideal approach focuses on establishing a dialogue between stakeholders and experts, where the experts can explain the uncertainty and the ways it is likely to be misinterpreted, the stakeholders can explain their decision-making criteria, and the two parties can work together to design a risk management strategy, answering each others' questions and concerns in an iterative fashion (Fischoff: Jacobs: NRC). But even outside such a format of stakeholder dialogue, scientists communicating uncertainty need to take into account the types of decisions that are likely to be made with their information, the particular uncertainties to which those decisions are most sensitive, the basic sources of the uncertainty in the information, and the ways in which those uncertainties are likely to be poorly understood or inconsistently interpreted (Morgan; Henrion: Plough; Krimsky: Webster). The remainder of this subsection provides more detail on each of these issues.

With climate change, the two classes of decisions to be influenced by scientific assessment are mitigation and adaptation. These differ across several dimensions, including the degree of political level of coordination and cooperation with which action is taken, and the temporal and spatial scale over which the effects of the decision will be felt (Schröter; Polsky *et al.* in press). Decisions for mitigation are often agreed upon by political elites, and legislated at the national or supra-national level. Adaptation, by contrast, is often undertaken at the local level, such that stakeholders—the people facing the consequence of the decision—are the decision-makers themselves (Kelly; Adger 2000). With this increased role of stakeholders in the climate change arena, the communication of impact, adaptation, and vulnerability assessment has become more important (Füssel; Klein in press: Jacobs). Stakeholders' adaptation decisions will depend on other types of changes outside the climate change arena (Turner, 2003), such as land use change and degradation (Luers; Lobell *et al.* 2003), and changing interdependence with trading partners (O'Brien; Leichenko *et al.* 2004), while their capacity to adapt will be limited by a mix of political, social, economic, and psychological factors (Adger 2000: Brooks; Adger 2004: Grothmann; Patt in press). Given the wide range of important factors and resulting complexity of the system being assessed, it is often necessary to narrow assessment to focus on a specific target community (Patt; Dessai 2005), or on the robustness of adaptation strategies to different types of uncertainty (Lempert; Nakicenovic *et al.* 2004). Finally, although some populations may be more skilled than others at interpreting uncertainty, it has been observed that a stakeholder's lack of education—or even literacy—does not necessarily mean that they are incapable of using information that contains uncertainty or is probabilistic (Patt 2001).

Since communicating uncertainty can be time consuming for the scientists and overwhelming for the audience, it is important for scientists communicating uncertainty to anticipate the particular types of uncertainty to which decisions will be most sensitive, and focus on these areas (Jones 2001). In the TAR, most uncertainty was communicated in terms of ranges of values (e.g. temperature by 2100). For many adaptation decisions, however, what is more important is the relative and changing likelihood of extreme events (Adger 1999: McBean 2004: O'Neill; Oppenheimer 2002). Where decisions are sensitive to expected levels of climate change decades or centuries in the future (such as investments in long term infrastructure), then human reflexive uncertainty—the actions that people take in response to their awareness of changing conditions—also becomes important, since important mitigation and adaptation decisions will be made in the intervening time (Dessai; Hulme 2003a). This kind of uncertainty is impossible to quantify, and the best approach is to present and quantitatively analyze qualitative storylines of the future in the form of alternate scenarios (Swart; Raskin *et al.* 2004). This was the approach taken by the SRES group of scenarios, and it has proven useful in stakeholder-driven vulnerability assessment (Schröter; *et al.* 2005). Scenarios bounding the high and low ends of anticipated change are important.

An important piece of uncertainty communication is the description of the factors that give rise to the uncertainty in the first place (Willows; Connell 2003a). Stakeholders will view information about uncertainty as more credible when they feel that they can make their own judgments about its quality and accuracy (Funtowicz; Ravetz 1990: Funtowicz 1993). It has been observed, for example, that people responded more frequently to seasonal climate forecasts when they understood some of the factors—such as El Niño—playing an important role in prediction (O'Brien, 2003; Patt, 2002). Experts quickly lose credibility when they make predictions that are wrong, when at the same time they appear less than honest in revealing their reasoning (Slovic 1993: Wynne 1996). People have an easier time remembering, and thus using, assessment of uncertainty when they can make a mental link between the uncertainty and events in the world that they can perceive and visualize; assessments of climate change uncertainty are more memorable, and hence more influential, when the fit into people's pre-existing mental maps of climate change, or when they discuss enough detail of the conditions giving rise to uncertainty as to help people to form new mental models (Hansen; Marx *et al.* 2004).

Finally, when uncertainty communicators take into account decision makers' mental models, they should try to anticipate some of the common pitfalls stakeholders have understanding and responding to uncertainty, in order to focus attention in the assessment process to overcome these challenges (Morgan; Fischhoff *et al*. 2001: Nicholls 1999). The following are some of the most important examples. First, people show more concern over risks where their probability of occurrence is unknown or ambiguous, compared to when it is well defined, understood, or quantifiable (Camerer 1992: Heath; Tversky 1991) This creates a challenge for climate change assessment of helping people to compare risks that are quantifiable and can be presented with probability density functions, and those that are not and must be evaluated with scenarios (Kandlikar; Risbey *et al*. 2005). Second, people's decisions are more sensitive to small changes in likelihood when the baseline probability is close to 0 or 1, compared to when it is a mid-range value, e.g. people respond more to the difference between a 1 in a million and 1 in a thousand risk than to the difference between a 30% and 40% likelihood (Kahneman; Tversky 1979). Third, when people interpret and remember risk assessments, they conflate assessed magnitude and likelihood of risks, meaning that the same language used to describe the likelihood of high and low magnitude events, or events with very different baseline probabilities, will be interpreted differently (Weber; Hilton 1990: Windschitl; Weber 1999). For example, it was found that the probability scale used widely in Working Group 1 of the TAR led to an overweighting of low magnitude outcomes compared to high magnitude ones, holding the assessed likelihood constant (Patt; Schrag 2003: Patt; Dessai 2005). Fourth, independent of assessed likelihood and magnitude, people are less willing to tolerate risks they perceive the risks as created by human agency or by natural forces beyond their control (Covello 1990: Ritov; Baron 1990). Thus they will likely view the risks associated with anthropogenic climate change or variability as qualitatively different than those caused by non-anthropogenic factors. Sixth, people tend to discount any single piece of expert opinion relative to their own prior beliefs (Yaniv; Kleinberger 2000), an effect which is mitigated when people learn of expert opinion through multiple independent sources (Weber 1997), and which is magnified when experts viewed as equally credible express disagreement (Cameron 2005).

2.2.3.3 Management of Uncertainty

Unless one believes that the uncertainties about climate change can all be reduced within a time frame before decision makers must take action, then the management of uncertainty is a necessary part of impact assessments aimed towards providing information for policy and decision-making. Managing uncertainty refers to taking account of uncertainty and integrating it into policy and decision-making processes (Schneider; Kuntz-Duriseti 2002). The appropriate quantification of uncertainty can also be viewed as part of the management process.

There have been numerous representations of the so-called "cascade of uncertainty" for climate change impacts (e.g. Jones 2000: Mearns; Hulme *et al*. 2001: e.g. Schneider 1983). The main components of the uncertainties include: uncertainties in future pathways of greenhouse gases and aerosols (which will be determined by future demographic, social, technological, and political developments on various spatial scales), determination of the atmospheric concentrations of the relevant gases and aerosols, conversions of the concentrations to forcing, and the response of the climate system to the forcing, plus the uncertainties attendant on the spatial scales of the models simulating the climate system (e.g., downscaling techniques). Other uncertainties include the evolution and effect of land-use/cover change, and the effects of climate changes on various societal and natural systems including adaptive responses triggered by climate changes. These latter have important feedbacks on the determination of emissions and other aspects of the climate system (e.g., surface albedo, roughness length). Some of these uncertainties may lend themselves to reduction in the near future (e.g., climate sensitivity) while others may be essentially irreducible such as the 100-year future pathway of technological change (Moser; Moss *et al.* 2004), or the uncertainty resulting from human agency (Ayres 1984). More detail on how different types of uncertainties have been treated in the climate change problem is discussed in section 2.3.4.5.

A number of studies focused on the climate system have used selected emissions scenarios as examples to drive probabilistic estimates of climate change that treat climate sensitivity as well as other factors as uncertain (e.g. Dowlatabadi, 1995; Allen, 2000; Knutti, 2002; Knutti, 2002 ; Stott, 2002). Studies deriving probabilistic representations of global emissions have been more controversial. Several studies have developed a pdf for emissions using the SRES scenarios as a basis, even though SRES authors explicitly did not assign relative likelihoods to scenarios. In almost all cases the decision has been to treat the individual scenarios as equally likely. For example, (New; Hulme 2000) assume that four SRES marker scenarios are equally likely in an analysis aimed at producing probabilistic climate change projections for the UK. Dessai(2001) take a similar approach but also consider intervention scenarios relative to the SRES baselines. (Wigley; Raper 2001b) use the full set of SRES scenarios and assume each is equally likely in an analysis aimed at producing a probabilistic projection of global average temperature change.

Some parametric uncertainties related to climate change can be quantified through development of pdfs (e.g., climate sensitivity). Uncertainties related to model configuration(e.g., missing feedbacks and processes in climate models, alternative models for technological change) are more difficult to characterize. As mentioned above, there is also a lack of consensus regarding how to handle uncertainty in some critical factors such as the pathway of future emissions of greenhouse gases and aerosols (Grübler; Nakicenovic 2001: Schneider 2001: 2002). An alternative to developing a single probability distribution for future emissions and/or climate change outcomes is to develop different conditional distributions whose comparison can be informative. (O'Neill 2004) developed conditional probabilistic emissions projections based on each of the four SRES storylines by treating population assumptions probabilistically. Results showed that considering the uncertainty in population within storylines leads to much wider ranges of emissions within the A2 and B2 storylines than represented in SRES. Distinctions (in terms of emissions outcomes) across storylines are also blurred. While uncertainty assessment of this sort can shed light on particular aspects of the climate problem, with some exceptions (e.g. Dowlatabadi 2002) assessments rarely *attempt* to cover the uncertainty space of the entire problem. Consequently, much of the probabilistic uncertainty information published thus far, should be viewed as tentative as opposed to the precise (though not necessarily accurate) characterization of likelihood that is typical of formal risk assessments of current environmental problems. This situation is not likely to change anytime soon.

There is, however, a wide array of decisions to be made to manage climate change, which requires a diverse range of information and attendant measures of uncertainty. Consequently decision-making under uncertainty is inevitable, since some of the uncertainties will likely remain poorly characterized and irreducible. Communication strategies and decision approaches that are robust in the face of the complex and deep uncertainties associated with climate change are needed. Kandlikar(2005) provide a schema for representing and communicating deep uncertainty on the climate problem that uses a hierarchical classification of pdfs and other measures (e.g. order of magnitude assessment, sign of outcomes) for communicating uncertainty that is commensurate with current scientific understanding. In a similar vein Casman (1999) have developed approaches to cope with situations where uncertainty grows so large that prediction or optimization no longer makes sense, and it may still be possible to use the model as a "behavioural test bed" to examine the relative robustness of alternative observational and behavioural strategies. Lempert and colleagues (Lempert; Schlesinger 2001), Lempert(2004) advocate a robust strategies approach to managing uncertainty. In this approach one eschews the limitations of prediction-based policy analysis (predict-then-act approach), and rather focuses on answering the question: what actions should be taken given that we cannot predict climate change? The focus then is to seek strategies that are relatively insensitive to uncertainty about future climate change. The robustness of such approaches depends on our ability to provide reasonable characterization of uncertainties in the form of pdfs. Consequently, this approach could lead to highly inefficient outcomes if we (falsely) place too much confidence in our ability to do so.

There are a number of points of view on the desirability, and credibility, of assigning subjective probabilities to alternative scenarios of future emissions and climate change outcomes. One view is that decision makers require estimates of the relative likelihood of different possible outcomes, and therefore it is not a question of whether probabilities will be assigned, but when and by whom. It is better that the assignment be made by experts than by users, since in this way well known biases in expert judgment can be controlled through decision analytic techniques (Schneider 2001: 2002: Webster; Babiker *et al*. 2002: Webster; Forest *et al*. 2003). An alternative view is that probabilities can be counterproductive because the climate change issue is characterized by "deep uncertainty" – i.e. system models, parameter values, and interactions are unknown or contested – and therefore elicited probabilities may not represent well the real world (Lempert; Nakicenovic *et al*. 2004), risking "dismissal of uncertainty in favour of spuriously constructed 'expert' opinion" (Grübler; Nakicenovic 2001). In addition, what type of information is most useful depends on the particular decision. For example, for some adaptation decisions, it may be more useful to focus on understanding and improving adaptive capacity than on improving probabilistic projections of climate change, and probabilities may be useful but not essential for making mitigation decisions (Dessai; Hulme 2003b). Consequently, managing uncertainty should be an integral part of the frameworks for characterizing and managing risks from climate change.

A recent example of a framework for managing climate change uncertainty in impacts is the decision framework developed by the UK Climate Impacts Programme in the United Kingdom (Willows; Connell 2003b), which aims to improve decision-makers’ capacity to handle risk about climate change. In this framework, decision-makers are encouraged to consider all relevant uncertainties to their decision-making context. This includes uncertainties regarding climate change, but also uncertainties regarding its impacts and performance of adaptation measures, an aspect of the problem that has been under-investigated. The risk-based framework consists of eight stages: identify the problem and objectives, establish decision-making criteria, assess risk, identify options, appraise options, make decision, implement decision, and monitor, evaluate and review effects of the decision.

An impacts threshold exceedence approach that focuses on the impact of uncertainties in local capacity to cope with an altered climate has been developed(Jones 2003: Jones 2001: Jones; Dettman *et al.* in press) and is discussed at length in section 2.2.1. Here risk is defined as the likelihood of exceeding the ability to cope with an altered climate (Jones 2003). Essentially thresholds of acceptable damage or loss (e.g., crop yield decrease, changes to the hydrologic cycle) are established which defines the coping range of the system. Change in the level of the resource under consideration based on climate change scenarios or probabilistic information about future climate can be calculated. Adaptation strategies are then evaluated based on maintaining the level of damage at or below the acceptable thresholds or coping range. This approach was sketched in the TAR (Ahmad; Warrick *et al*. 2001: Carter; La Rovere *et al*. 2001: Mearns; Hulme *et al*. 2001) but has undergone much more extensive development (see section 2.1.1).

2.3 Characterising the future

2.3.1 Introduction

2.3.1.1 Why and how do we characterise future conditions?

Any attempt to evaluate future climate change impacts, adaptation and vulnerability requires some assumptions about how the future will develop. Some of the underlying human driving factors contributing to environmental change include population growth, economic development and the unsustainable exploitation of natural resources. In order to be able to estimate the future implications of environmental change, it is necessary to project these socio-economic driving forces into the future. However, there are formidable uncertainties associated with estimates of future human behaviour, so precise forecasts of future trends are not possible. An alternative approach is to construct *scenarios*.

The scenario approach is widely used in many sciences (physical, economic, and social) in varied circumstances and for different purposes (Alcamo 2001: Carter; La Rovere *et al*. 2001). Scenario thinking may offer solutions to complex issues for which there appears to be no simple analysis (Davis 2002). Scenarios are coherent, credible stories about alternative futures. Importantly, scenarios are not projections, predictions or preferences of the future (see Box 2.2). Instead, the main idea of the scenario approach is to use multiple perspectives to explore a specific problem.

In the context of climate impact, adaptation and vulnerability assessments, a scenario can be defined as "a coherent, internally consistent and plausible description of a possible future state of the world" (Carter; La Rovere *et al*. 2001: IPCC 1994). Other definitions have emerged in recent years in the wider context of global change and sustainable development. For example, the Millennium Ecosystem Assessment (MA) describes scenarios as “plausible alternative futures, each an example of what might happen under particular assumptions” (MA 2002). This definition highlights the MA’s understanding of scenarios as a method to challenge one’s beliefs about the future. (Schwartz 1996) points out the usefulness of scenario development for decision-making and calls scenarios "a tool for ordering one’s perceptions about alternative future environments in which one’s decision might be played out". Raskin(forthcoming) describes scenarios as "plausible stories about how the future might unfold from existing patterns, new factors and alternative human choices. The stories can be told in the language of both words and numbers." This definition draws attention to the narrative, dynamic character of scenarios, grounding the stories in the many facets of today’s reality. The IPCC highlights the understanding of the factors of change, their dynamics and interactions by describing scenarios as "plausible descriptions of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces" (Nakicenovic; Alcamo *et al*. 2000).

2.3.1.2 Non-scenario approaches

Not all CCIAV assessments require a scenario component. In some cases, it may be sufficient that system sensitivities are explored without making any assumptions about the future. For example, an understanding of the regional vulnerability to El Niño is a prerequisite for evaluating the likely consequences of a change in frequency of such events. A lot of information can be obtained on the vulnerability and adaptive capacity to such climatic variations simply using data from past events. Although scenarios might be helpful in indicating the likely trends in ENSO-events, they are probably not essential. From the point of view of adaptation, efficient coping strategies for the events when they occur combined with skilful short-term forecasting of their onset and decay, may well be the most effective responses to such possible future changes. Such an approach was adopted to investigate factors contributing to vulnerability to dengue fever in Jamaica (Heslop-Thomas; Bailey *et al*. forthcoming), vulnerability to multiple stresses in the Miombo Region (Desanker, forthcoming, vulnerability to multiple stresses), and vulnerability of food supply to drought in North Darfur State, Sudan (Sanjak; Osman *et al*. forthcoming).

There is also a growing body of CCIAV studies that adopt characterisations of the future that cannot be described *senso stricto* as scenarios, either because they are based on implausible assumptions about the driving forces affecting future conditions and/or because the outcomes portrayed are themselves implausible. Examples of such characterisations include:

(i) *incremental adjustments for sensitivity analysis*, where particular climatic (or related) elements are altered by arbitrary amounts, often regularly spaced across a range of possible future changes. The adjustments are commonly applied to study the sensitivity of an exposure unit to a wide range of variations in climate and to construct impact response surfaces over multivariate climate space. However, though they are referred to as scenarios in the TAR (Carter; La Rovere *et al*. 2001), and while they are intended to be realistic in magnitude, these adjustments rarely offer a plausible seasonal or regional representation of likely future conditions.

(ii) *hypothetical characterisations for illustrating impacts and vulnerability*, where future conditions are depicted that are themselves implausible, but may nevertheless be instructive for studying or for communicating potential impacts and adaptation responses. Two types of hypothetical situation have been examined in the recent literature: one type illustrates the committed changes already inherent in the climate system due to historical greenhouse gas forcing; the second describes singular events with widespread consequences.

Commitment runs refer to climate change projections that assume that the radiative forcing at a particular point in time (often the current forcing) is held constant into the future (see Chapter 10, Working Group I). These projections demonstrate an important characteristic of the climate system: under conditions of changing radiative forcing, at any point in time some fraction of the climate change that would eventually result from the observed level of forcing has not yet been realized. It can take several decades for global average temperature to equilibrate with a given level of radiative forcing, a timescale dictated primarily by the penetration of heat into the surface ocean (Hansen; Russell *et al*. 1985: Hoffert; Callegari *et al*. 1980: Wigley; Raper 1993). Recent experiments offer estimates of the global mean annual warming commitment associated with radiation forcing in 2000 of between ?? and ??°C (WG I, Chapter 10, to be added later). This compares with values of between 0.2 and 1.0°C in previous studies (Hansen; Russell *et al*. 1985: Hansen; Sato *et al*. 2002: Hare; Meinshausen 2004: Meehl; Washington *et al*. 2005: Wetherald; Stouffer *et al*. 2001: Wigley 2005: Wigley; Raper 1993). Sea level rise responds much more slowly, on a timescale of millennia, dictated by the penetration of heat into the deep ocean (Church; Gregory *et al*. 2001: Wigley; Raper 1993). Committed sea level rise has been estimated at between ?? and ??m for current forcing levels (WG I, Chapter 10 – add later), comparable to previous estimates of 0 – 30 cm per century for the next several centuries (e.g. Meehl; Washington *et al*. 2005: Nicholls 2004: e.g. Wigley 2005). Commitment runs are useful diagnostic tools for comparing the responses of different climate models, and can also demonstrate the inherent lag in response of the climate system to the historical build-up of GHGs, expressing the magnitude of climate and sea-level change to which the earth is already committed and to which nature and society must adapt. However, as scenarios they are unrealistic. For example, the emissions reductions required to stabilize radiative forcing at current levels are far outside the range of even the most extreme mitigation scenario. Thus radiative forcing will continue to increase in the coming decades even under a stringent policy scenario, implying that the world is committed to more warming than shown in commitment runs. Commitment runs are therefore not appropriate as baselines against which to measure impacts resulting from plausible emissions and climate change scenarios.

Singular events with widespread consequences, are extreme, often irreversible changes in the earth system which are regarded as theoretically plausible, but about which little is known. These include events such as an abrupt cessation of the North Atlantic thermohaline circulation (THC) leading to climatic cooling over northwest Europe, or the disintegration of the West Antarctic Ice Sheet (WAIS) causing rapid global sea-level rise. The scientific understanding of the mechanisms required to initiate either of these events is poor (cf. Chapters 8 and 10, WG I), hence realistic scenarios cannot be constructed. However, the potentially high magnitude of their impact, were they to occur, has provoked much concern among decision makers and prompted CCIAV assessors to attempt their characterisation using whatever information is available. A separate discussion of these is included in section 2.3.2.5 alongside other scenario approaches, although they should strictly be regarded as "thought experiments" rather than scenarios.

2.3.1.3 The role of scenarios in decision making

Scenarios serve a wide range of roles for research, education and decision making, and the development and application of environmental change scenarios has been widely reported e.g. Alcamo, 1996; Rotmans, 2000; Mearns, 2001; Nakićenović, 2000; Leemans, 1999; Carter, 2001. A number of uses for scenarios in policy-orientated environmental assessments are identified by (Alcamo 2001), in particular to:

- provide a picture of future alternative states of the environment;
- raise awareness about the future connection between different environmental problems;
- illustrate how alternative policy pathways can achieve an environmental target;
- combine qualitative and quantitative information about the future evolution of an environmental problem;
- identify the robustness of environmental policies under different future conditions;
- help stakeholders, policymakers and experts to account for the large time and space scales of a problem;
- help raise awareness of new or intensifying environmental problems.

Some of the more common characteristics of scenarios are summarised in Box 2.3.

Scenarios are commonly required in climate change impact, adaptation and vulnerability assessments to provide alternative views of the future conditions thought likely to influence a given system or activity. In the TAR, scenarios of five classes of changes were distinguished and described: socio-economic factors, land use and land cover, other (non climatic) environmental factors, climate, and sea level (Carter; La Rovere *et al*. 2001), with climate scenarios covered in more depth by (Mearns; Hulme *et al*. 2001). This classification is retained here for characterising the future conditions assumed in many of the studies evaluated in this Report.

The next section (2.3.2) discusses advances in the construction of scenarios, focusing on new approaches to scenario development that are of relevance to CCIAV at global and regional scales. Section 2.3.3 then offers an overview of scenarios widely adopted in recent CCIAV studies that are based on the global scenarios described in the IPCC Special Report on Emissions Scenarios (SRES). Scenarios that assume mitigation, including the special case of stabilisation of greenhouse gas concentrations are treated in section 2.3.4, and examples are provided in section 2.3.5 of how these new scenarios have provided new insights for CCIAV analyses compared to previous assessments.

Box 2.2: Scenario definitions

Projection. The term "projection" is used in two senses in this chapter. In general usage, a projection can be regarded as any description of the future and the pathway leading to it. However, a more specific interpretation is often attached to the term "climate projection" when referring to model-derived estimates of future climate.

Forecast/Prediction. When a projection is branded "most likely" it becomes a forecast or prediction. A forecast/prediction is often obtained using deterministic models, possibly a set of these, outputs of which can enable some level of confidence to be attached to projections. It can be defined as the best possible estimate of future conditions based on current conditions, assumptions about drivers, and the probability that the model itself is correct (Clark; *et al*. 2001).

Scenario. A scenario is a coherent, internally consistent and plausible description of a possible future state of the world (IPCC 1994). It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. Scenarios can portray changes in the future that depart in a plausible way from today's boundary conditions. In this way scenarios are also useful for thinking about dynamic processes and causal chains that affect the future (Rotmans, 2000), which might result in challenging our beliefs and assumptions about how social and ecological systems work. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in projections. Other terms that are sometimes used as synonyms for scenarios are *characterisations* (cf. Section 2.3.3) and *storylines*.

Baseline/Reference. The baseline (or reference) is any datum against which change is measured. It might be a "current baseline", in which case it represents observable, present-day conditions. It might also be a "future baseline", which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.

Storyline. A storyline is a narrative description of a scenario which highlights its main features and the relationships between the scenario's driving forces and its main features (Alcamo 2001). To ensure the credibility and legitimacy of storylines an iterative procedure is usually required to construct them, involving scenario writers, experts and stakeholders and often involving intensive discussions, compromises and considerable effort (Alcamo 2001). There are thus clear advantages in adopting existing, accepted storylines. For example, this thinking has been a major motivation for the adoption of SRES scenarios in many of the recent CCIAV studies assessed in this report.

Box 2.3: Some characteristics of scenarios

Exploratory vs. normative scenarios

Exploratory (or descriptive) scenarios describe how the future might unfold according to known processes of change, or as extrapolations of past trends (Carter; La Rovere *et al*. 2001). They are sometimes described as "business-as-usual" scenarios, often involving no major interventions or paradigm shifts in the organisation or functioning of a system. However, the term business-as-usual may be misleading, as exploratory scenarios can also describe futures that bifurcate at some point or that make some assumptions about regulation and/or adaptation of a system. The simplest model is a direct extrapolation of past trends. *Normative (or prescriptive)* scenarios describe a pre-specified future, either optimistic, pessimistic or neutral (Alcamo 2001), presenting "... a picture of the world achievable (or avoidable) only through certain actions. The scenario itself becomes an argument for taking those actions" (Ogilvy 1992) and each scenario can explore a specific set of measures and policies to reach the pre-specified future. Normative scenarios span a wide spectrum from simple, single issue scenarios (e.g., "worst case" scenarios that explore the impacts of extreme climate events) to complex, multi-dimensional scenarios constructed to meet the constraints of a prescribed, target world (e.g. scenarios constructed to constrain emissions within prescribed bounds that avoid inducing a critical climate change). Often, the construction of such scenarios requires the use of *inverse methods*.

Qualitative vs. quantitative scenarios

Scenarios can be either qualitative or quantitative (Alcamo 2001). *Qualitative* scenarios describe the future in the form of words, phrases, visual symbols or diagrams, rather than numerical estimates. Most commonly, however, they comprise narrative accounts of the future, or *storylines*. Well constructed qualitative scenarios can offer an interesting and readily understandable medium for communicating information about the future. The storyline construction allows, in addition, for creative thinking that explores the boundaries of our current knowledge and enables the incorporation of features that are often hard to model, such as surprises and feedback loops. However, they also inevitably suffer from a lack of numerical precision in describing trends in important variables, and are based on a set of subjective, undocumented and unspoken assumptions originating from the scenario developers. *Quantitative* scenarios, in contrast, do attach numerical quantities to future trends, presented as graphs or tables, and often based on outputs from computer models. These have the advantage of being transparent to the extent that the modelled relationships are usually documented (e.g. as mathematical equations), values are reproducible, and results are often already published, and hence subject to scientific scrutiny. However, by attaching numbers to developments that are by nature uncertain, they can be criticised for conveying a false sense of accuracy. Models themselves are often too technical for non-specialists to understand, and may also contain implicit assumptions that can bias the scenarios and narrow the range of possible outcomes (Alcamo 2001)}. Recent global scenario exercises have started to combine both qualitative and quantitative methods for scenario development. By combining the creative thinking possible in the qualitative storyline development and quantifying the assumptions and parts of the storylines for which models exist, the advantages of both approaches can be combined. The result can be challenging scenarios with interesting stories that are nevertheless tested for their consistency and plausibility based on our existing knowledge.

Inverse modelling approaches (e.g. tolerable windows, safe emission corridors)

In recent years there have been intensive efforts to specify normative emissions targets that avoid the exceedence of critical thresholds of climate change that would cause unacceptable impacts. These efforts invoke an *inverse modelling approach,* which first defines the constraints on emissions that are not to be exceeded, and then works backwards using models to compute if there exist corridors of long-term emissions paths that satisfy the specified policy constraints (Toth 2003). Inverse methods have spawned concepts such as "safe emissions corridors" (Alcamo; Kreileman *et al*. 1996) and "guardrails" (e.g. Dowlatabadi, 1999), and have been further elaborated into the "tolerable windows approach" (Toth 2003: WBGU 1995), which analyses climate protection strategies that seek to avoid both unacceptable impacts of climate change and intolerable social costs of emissions reductions.

2.3.2 Advances in scenario development

An important development since the TAR has been the construction of non-climate futures and their integration with climate scenarios in CCIAV studies. CCIAV studies have now moved on to consider multiple stresses and drivers rather than climate impacts in isolation. This has important implications for the assessment of adaptation and vulnerability to climate change, as response measures that address non-climate stresses also have potential implications for climate impacts. Moreover, in some cases the inclusion of non-climate futures in CCIAV studies can transform the character and interpretation of the results (Arnell; Livermore *et al*. 2004).

An area of particular progress has been in the development of land use change scenarios at both global and regional scales within the SRES and other scenario logical frameworks. Land use change is important in terms of mediating climate change impacts on the wider environment (e.g. impacts on ecosystems, agriculture, water resources, etc. Zebisch; Wechsung *et al*. 2004), as well as having implications for mitigation strategies (e.g. C sequestration).

2.3.2.1 Global scenarios and storylines

Scenario analysis has been in common use for international environmental assessments since about the 1980s, though its origins date back to the 1960s (Alcamo 2001). There have been several initiatives by the IPCC to develop emissions scenarios for greenhouse gases and aerosols (IPCC 1990: Nakicenovic; Alcamo *et al*. 2000: Pepper; Leggett *et al*. 1992) and subsequent use of these scenarios to produce derivative scenarios of atmospheric composition, climate and sea level. Scenarios derived from the most recent of these, the IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic; Alcamo *et al*. 2000), have been widely adopted in CCIAV studies reported in this volume. For this reason, the SRES scenarios are described in more detail in Section 2.3.3. In the remainder of this section, examples are presented of other global scenario exercises that have a substantial environmental component and are also available for application in CCIAV-related assessments, based on a comprehensive overview by (Raskin forthcoming).

Global Scenarios Group (GSG)
The GSG is an interdisciplinary, independent effort, established in 1995 by the Stockholm Environment Institute to develop a set of global scenarios that portray a wide range of societal,

economic, political and environmental changes[4]. The storylines are backed-up by a set of quantifications, using the PoleStar System developed to synthesize global data sets across the interactions of different variables (Raskin; Heaps *et al*. 1999). The group developed three archetypal scenarios of the future out to 2050 (e.g. Raskin 2002): (i) *Conventional Worlds* (current trends play out without major discontinuity and surprise in the evolution of institutions, environmental systems and human values), (ii) *Barbarization* (fundamental social change occurs, but is unwelcome, bringing great human misery and collapse of civilized norms), (iii) *Great Transitions* (fundamental social transformation but to a new and arguably higher stage of human civilization). For each of the broad classes two different variants were developed.

Global Environmental Outlook (GEO-3 and GEO-4)
The third Global Environmental Outlook (GEO-3), organized by the United Nations Environment Programme (UNEP), developed scenarios over a 30 year time horizon based on four of the GSG scenario variants and also using inputs from the SRES scenarios. These scenarios, called *Market First*, *Policy First*, *Security First* and *Sustainability First*, portray a variety of imaginable socio-economic and political changes and focus on their environmental consequences. The scenarios were created through an elaborate process of integrating global and regional information via a set of global and regional meetings, thereby enriching and ground-truthing the global storylines with a lot of additional regional information (Raskin; Kemp-Benedict 2002). UNEP is currently working on developing the next GEO to be released in 2007, which will also include updated global scenarios up to the year 2050. For that the GEO team decided to enrich the existing GEO-3 storylines with more regional detail (based on an elaborate regional consultation process), incorporate new research findings from other assessments, improve the quantification efforts and explore specific feedbacks between society and the environment in a more rigorous manner.

World Business Council on Sustainable Development (WBCSD)
The WBCSD developed three scenarios for 2050 in an open process involving representatives from 35 organizations (WBCSD 1997). Their aim was to engage the business community in the debate on sustainable development. The implications and challenges of a wide range of plausible futures for the private sector are explored and possible lessons drawn. The three scenarios were labelled: *FROG!* (Market-driven growth, economic globalization), *GEOPolity* (Top-down approach to sustainability) and *Jazz* (Bottom-up approach to sustainability, ad hoc alliances, innovation).

Organisation for Economic Co-operation and Development (OECD)
The OECD developed a baseline scenario for its Environmental Outlook based on development projections to 2020, complemented by several policy variants such as removal of subsidies and introduction of eco-taxes (OECD 2001). The focus is on critical environmental concerns facing OECD countries, though the study is global in scope. OECD is currently developing a Second Environmental Outlook to be released in 2007. The study, with a time horizon up to 2030, takes a closer look at possible future environmental policies of OECD countries addressing specifically the question of the cost of policy inaction with respect to dealing with environmental degradation.

Millennium Ecosystem Assessment (MA)
The MA is an international scientific effort, which aimed to assess the consequences of ecosystem change for human well-being[5]. The MA built a set of four global scenarios to 2050 (for some variables such as climate change reporting is done up to 2100) addressing plausible changes in ecosystem services and their outcomes for material as well as other components of human well-

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[4] http://www.gsg.org/

[5] http://www.millenniumassessment.org/

being and health. These are labelled: *Global Orchestration* (a globalised world with emphasis on economic growth and public goods and a reactive approach to dealing with environmental problems), *Order from Strength* (regionalized with emphasis on national security and economic growth, reactive approach to ecosystem management), *Adapting Mosaic* (regionalized with emphasis on local adaptation and flexible governance, proactive ecosystem management approach), and *TechnoGarden* (globalized with emphasis on green technology and proactive ecosystem management). These bear some resemblance to the SRES storylines A1, A2, B2 and B1, respectively, but are distinguished from them by their focus on alternative approaches to sustaining ecosystem services. In particular, the MA exercise aimed to introduce the consideration of ecological dynamics into global scenario analysis, which had previously been identified as one of the gaps in environmental scenario analysis (Cumming; Alcamo *et al*. in press).

World Water Vision (WWV)

The WWV presents three global water scenarios for 2025 that focus on issues of water supply and demand, conflict over water resources and water requirements for nature (Cosgrove; Rijsberman 2000). The three scenarios: *Business-as-Usual* (current water policies continue, high inequity), *Technology, Economics & the Private Sector* (market-based mechanisms, better technology), and *Values and Lifestyles* (less water-intensive activities, ecological preservation) were developed by the World Water Council to increase awareness of a rising global water crisis.

These scenarios are compared to the SRES scenarios in Table 2.4. A comparison of the SRES and GEO-3/GSG scenarios for population and GDP per capita is given in Figure 2.5. A common feature of all these exercises is that they were developed in a multi-step process, named "Storyline-and-Simulation" by (Alcamo 2001). In this approach, first a set of qualitative storylines are developed which each describe the main uncertainties, the key driving forces of changes and their interactions in an internally consistent story. This facilitates the involvement of a variety of non-scientific stakeholders. In subsequent steps these storylines are translated into quantitative input variables for an integrated modelling exercise, if models exist for this. The modelling then helps to ground-truth the main assumptions made in each storyline. In an iterative process, the model results and the storylines are harmonized. In a number of concluding steps, draft scenarios are distributed for general review by stakeholders and experts before final publication and release.

Table 2.4: *Comparison of SRES with other selected global scenarios using the GSG scenario structure as a framework (revised from an unpublished report for the Millennium Ecosystem Assessment)*

SRES 2100	**WBCSD 2050**	**WWV 2025**	**GSG 2050**	**GEO-3 2032**	**OECD 2020**	**MA 2100**
			Conventional Worlds			
A1	*FROG!*	*BaU*	*Market Forces*	*Markets First*	*Reference*	*Global Orchestration*
B1	*GeoPolity*	*Technology & economics*	*Policy Reform*	*Policy First*	*Policy variants*	*TechnoGarden*
			Barbarization			
A2			*Breakdown*			
			Fortress World	*Security First*		*Order from Strength*
			Great Transitions			
B2			*Eco-communalism*			*Adapting Mosaic*
	Jazz	*Lifestyle & values*	*New sustainability paradigm*	*Sustainability First*		

2.3.2.2 Linking scenarios at global and regional scales

The issue of the geographical scale of a scenarios exercise and if and how to link scenarios across scales is not yet well developed in the scenarios community. The scale of a scenario needs to match the scale of the most important processes and dynamics in space and time that it is designed to represent. Quite often, information is required at a range of scales, thus these too need to be captured by the exercise. Moreover, the linkages between scenarios at different scales may be critical to ensure consistency of assumptions in an assessment.

Different possibilities have been explored by the Millennium Ecosystem Assessment, which operates at a range of scales, of how scenarios can be nested within each other to create a set of multi-scale scenarios:

- The storylines developed at one scale can be played out at another scale.
- The scenarios developed at a higher scale can be used as boundary conditions for lower scale scenarios, which then develop their own storyline. Here for example the trends described for the major driving forces at the global scale can be used for describing the range of variability these drivers exhibit at a regional level.
- The scenarios developed at a higher scale can be used to create scenarios about policy and management options currently discussed at a lower scale.
- The underlying assumptions and world views played out in the scenarios developed at one level, can be applied to developing scenarios at another level.

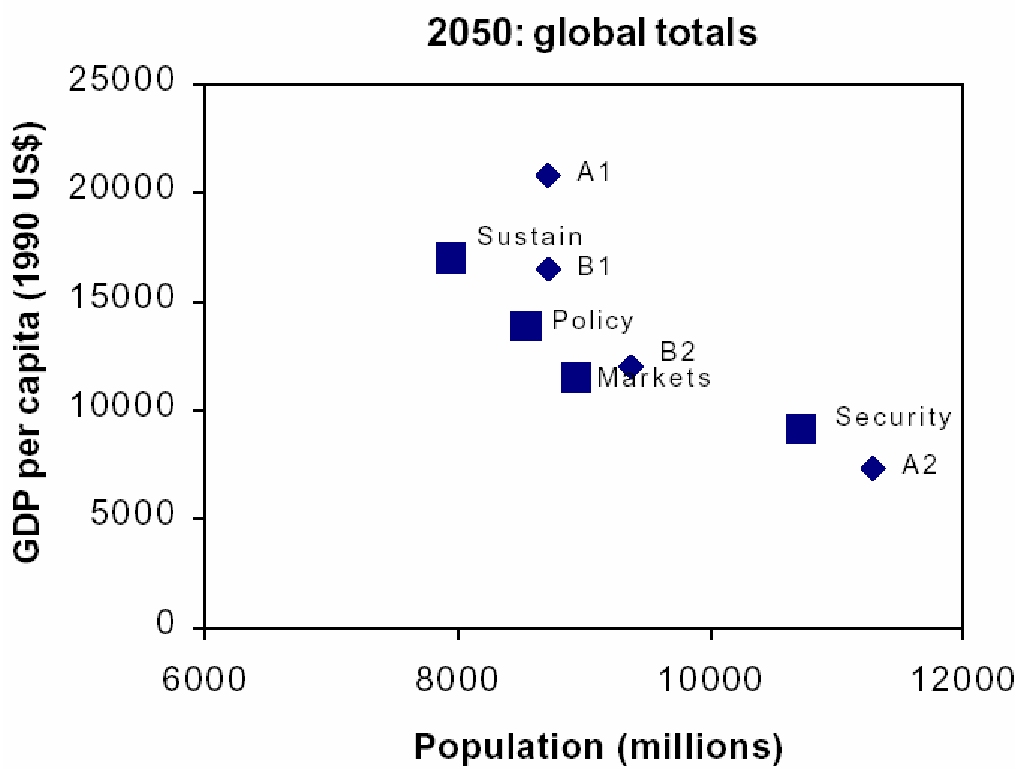

Figure 2.5: *Global population and GDP per capita under the four SRES scenarios (diamonds) and four GEO-3/GSG scenarios (squares) for 2050 (Arnell et al. 2004).*

Nesting scenarios within each other is not an easy process, particularly if the scenarios are supposed to be relevant to user groups at the different scales. However, attempts have been made for example by the European MedAction project, the VISIONS project and the MA, using either one or various of the described approaches. In general, though the issue of multi-scale scenarios still requires further investigation for deepening our understanding of suitable methods and their utilization.

2.3.2.3 Regional scenarios of climate, sea level and atmospheric composition

Regional projections of climate, sea level and atmospheric composition are treated at some length in chapters of the Working Group I Report, however it is the application and interpretation of such information that is of importance for CCIAV assessment. Approaches to regional scenario development were described in the TAR (Carter; La Rovere *et al*. 2001: Mearns; Hulme *et al*. 2001) so only advances since the TAR are reported here.

Development and application of high resolution scenarios

Since the TAR there has been rapid development and application of scenarios from regional models and statistical downscaling. Some of this work further confirms points made in the TAR, that higher resolution allowed more realistic response of the climate model to high resolution topographic features (lakes, mountains, coastlines), and that in general different results with impacts models were produced depending on whether the high resolution RCM scenario, or the GCM scenario was used (e.g. Arnell; Hudson *et al*. 2003: Leung; Qian *et al*. 2004: Mearns; Carbone *et al*. 2003: Stone; Hotchkiss *et al*. 2003: Wood; Leung *et al*. 2004). In general these experiments still concerned only one driving AOGCM and only one or two regional models. The development of more elaborate and extensive AOGCM-RCM programs has allowed for more complete analysis of the implications of higher resolution climate scenarios. In particular, it became possible to explore multiple uncertainties (across different RCMs, AOGCMs, and emissions scenarios) and the effects of these scenario uncertainties on impacts work. The PRUDENCE project in Europe resulted in multiple RCM simulations based on two different AOGCM or AGCM simulations and two different emissions scenarios. In the impacts studies that used these simulations (e.g. Fronzek; Carter 2005: e.g. Graham; *et al* in prep.: Olesen; Carter *et al*. 2005) much more elaborate statements could be made regarding the uncertainty due to the spatial scale of the scenarios, and the uncertainty resulting from different RCMS, versus different GCMs. For example, Oleson *et al*., using scenarios from a range of RCMs and GCMs, and two emissions scenarios, found that the variation in simulated impacts (agricultural) was smaller across RCMs nested in a single GCM than across different GCMs or across the different scenarios. This type of analysis can point the way to more efficient use of resources for scenario development based on where the largest uncertainties are found.

In addition, the resolutions of regional climate scenarios have increased (now often finer than 50 km) and this has encouraged the undertaking of new studies. For example, studies examining the combined impacts of increased heat stress and air pollution under future climate is now much more feasible because the resolution of the regional models is now more commensurate with that of air quality models (e.g. Hogrefe; Lynn *et al*. 2004). Finally scenarios developed from RCMs are now being used in many more regions of the world, particularly the developing world (e.g., Anyah; Semazzi 2004: Arnell; Hudson *et al*. 2003: Gao; Li *et al*. 2003: e.g., Kumar 2005).

Much additional work has been produced using methods of statistical downscaling for climate scenario generation (see Working Group I, Chapter 11, section 11.2.1.4). Various SD techniques have been used in downscaling directly to (physically based) impacts and to a greater variety of climate variables, including extremes of variables. For example, Wang (2004) and Caires (2005) have developed non-stationary extreme value models for projecting changes in wave height.

While generally statistical downscaling has been used to develop climate change scenarios at single locations, Hewitson (2003) developed empirical downscaling for point scale precipitation at numerous sites across the continent of Africa and on a .1 deg. resolution grid over Africa. Finally, the availability of statistical downscaling tools is making it easier for more researchers to apply the technique for scenario development, for example the SDSM tool of Wilby (2002), which has been used to produce scenarios for islands in the Caribbean (Chen; Rhoden *et al*. 2004), and for the River Thames basin (Wilby; Harris 2005 (accepted)).

Probabilistic representations of climate change

Since the TAR, many studies have produced probabilistic representations of climate change which can be useful for impacts assessment. Some studies consider the 'integrated climate change context' in that they include uncertainties in the climate system (usually represented through key climate model parameters such as climate model sensitivity) as well as uncertainties in future emissions, while others consider only subcomponents of the problem. Key choices in these studies are which components of the problem to treat as uncertain, and how to define the probability density functions (pdfs) for those components

In the integrated approach, the development of probabilistic representations (or projections) of climate change is typically based on the derivation of probability density functions (pdfs) for emissions and for parameters in models of greenhouse gas cycles, radiative forcing, and the climate system. The models are then run many times, sampling from the uncertainty distributions for inputs and model parameters, in order to produce a pdf of outcomes, e.g. global temperature and precipitation change. For the most part, these integrated studies have used either simple climate models (e.g. Wigley; Raper 2001b) or climate models of intermediate complexity (Forest; *et al*. 2002). Complete AOGCMs have so far not been used for these integrated approaches.

One of the most important climate parameters investigated in a probabilistic mode is climate model sensitivity, which can be viewed as the intensity of the climate model response to a given forcing. The standard metric in the context of the IPCC has been the response of the climate model to a doubling of CO_2. Numerous studies (e.g., Andronova; Schlesinger 2001: Forest; al. 2002: Gregory; al. 2002: Murphy; Sexton *et al*. 2004) have come up with estimates of pdfs for climate sensitivity using various techniques including expert judgment. Most have used simple and medium complexity models, but most recently (Murphy; Sexton *et al*. 2004) estimated a pdf of climate sensitivity using a full GCM. Their estimate of the 95% confidence interval, based on sampling of the model parameter space and producing a 53 member ensemble, is 1.9-5.3 ^{o}C. Climate sensitivity was the subject of a recent IPCC Working Group 1 workshop (IPCC 2004). It is also extensively discussed in Chapter 10 on global climate projections in the Working Group 1 Report.

A number of studies focused on the climate system have used selected emissions scenarios as examples to drive probabilistic estimates of climate change that treat climate sensitivity as well as other factors as uncertain (e.g., Allen; Stott *et al*. 2000: Knutti; al. 2002: Stott; Kettleborough 2002). Alternative viewpoints on the use of subjective probabilities are discussed in Section 2.2.3.3.

While there have been numerous articles in the past few years on the global scale for quantifying uncertainties, much less has been produced on the regional scale, a scale, arguably of greater relevance for impacts use. Some early work on generating regional probabilities was covered in the TAR (e.g. Jones 2000: New; Hulme 2000).

More recently, Giorgi (2002) calculated regional uncertainties in changes in temperature and precipitation simulated by 9 AOGCMs run with the A2 and B2 SRES scenarios, and produced probabilities using the REA method (Giorgi; Mearns 2003). In this method relative weightings of the AOGCM results are determined by model biases and degree of convergence for the model projections for climate change. Tebaldi (2004) and Tebaldi (2005) took the basic features of the REA method and developed a full Bayesian probabilistic model of regional climate change, conditioned on the individual SRES scenarios. They also tested the relative importance of the convergence criterion. Greene (2005 (submitted)) also produced a Bayesian model using the suite of models that ran several SRES scenarios for the AR4, but eliminated a number of the CGMs from the data set based on poor model performance. Räisänen (2005 (submitted)) developed a method that weighted the models equally. Each of these methods develops separate PDFs for each emission scenario that is considered. See Chapter 11 of the Working Group I Report for a more complete assessment of these methods.

The methods described in the preceding paragraph relied on multi-model ensembles. It should be noted that the probabilistic descriptions from any of these techniques do not consider all the known uncertainties regarding the future climate. The probabilities in this regard should be viewed as relatively conservative, i.e., representing the lower limit of uncertainty about future regional climate.

Dessai(2005(accepted)) apply the idea of simple pattern scaling (Santer; Wigley *et al*. 1990), to a super ensemble of AOGCMs. They "modulate" the normalized regional patterns of change by the global mean temperature changes generated under many SRES scenarios and climate sensitivities through MAGICC, a simple probabilistic energy balance model (Wigley; Raper 2001a). Thus, they can estimate PDFs of regional change on the basis of a high number of samples. The focus of their work is measuring the changes in PDFs as a function of the different sources of uncertainty.

Other groups are in the process of developing additional methods of establishing probabilities of regional climate change. For example, the European ENSEMBLES research project[6] is applying, among others, the 53 member ensemble of (Murphy; Sexton *et al*. 2004) to produce regional probabilities of climate change.

Methods are also being developed to translate probabilistic climate changes for use in impacts assessment (e.g., New; Hulme 2000: Wilby; Harris 2005(accepted): Yates; Tebaldi *et al*. in preparation). Others have been developed using probabilities of impacts threshold exceedences (e.g., Jones 2003: e.g., Jones 2000: Jones; Dettman *et al*. in press), which can be calculated without a full probabilistic representation of the climate. Wilby(2005(accepted)), for example, developed a probabilistic framework (using Monte Carlo techniques) for combining information from various sources of uncertainty (emissions scenarios, GCMs, and hydrological model parameters) in a study of probabilities of low flows in the River Thames basin. The GCM outputs were statistically downscaled using the Statistical DonwnScaling Model (SDSM) and these were applied to the CATCHMOD water resource model. Through establishing the cumulative

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[6] http://www.ensembles-eu.org/

distribution function of 95% exceedence of River flow they found that the most important uncertainty was the difference among the GCMs.

Scenarios of extreme climate events

Placeholder: Some important recent advances in the downscaling of extremes will be briefly summarised here following a meeting with WG I, Chapter 11

Sea level scenarios

One of the major impacts projected under global warming is sea-level rise. Klein (1999) suggested three levels of analysis for sea-level rise impacts, which demand increasingly sophisticated scenarios for analysis:

- Screening assessment, to determine whether sea-level rise is a potential problem. An arbitrary scenario of sea-level rise is usually sufficient for this exercise (e.g. the widely adopted scenario of a uniform 1-m rise in relative sea level, following the recommendations of the IPCC Common Methodology – (WCC'93 1994).
- Vulnerability assessment, to understand the potential impacts of sea-level rise. This requires a range of sea-level rise scenarios possibly combined with other relevant climate scenarios. Commonly such a step would rely on scenarios of global mean sea level change, usually superimposed on local information about land movements.
- Planning assessment, for developing adaptive responses to sea-level rise and climate change impacts. This requires a comprehensive set of sea-level rise scenarios combined with other appropriate climate change scenarios.

Some of the basic techniques for developing sea level scenarios were described in the TAR (Carter; La Rovere *et al*. 2001), where examples were mainly drawn from screening or vulnerability assessments. Since the TAR there have been new efforts to refine sea level scenarios to account for regional and local effects and to make studies more relevant for planning purposes. Two main types of scenarios are distinguished here: regional scenarios and scenarios of storm surges. A third type, characterising abrupt sea level rise, is described in section 2.3.2.5. More details on sea level and sea level scenarios can be found in Chapters 5 and 10 of the WG I report and Chapter 6 of this report.

Regional sea level scenarios. Sea level does not change uniformly across the world due to climate change: different rates of oceanic thermal expansion and region-specific changes in oceanic and atmospheric circulation affect the level of the sea surface differently, giving rise in AOGCM simulations to regional departures of up to 50% from global-mean sea-level rise (Church; Gregory *et al*. 2001: Gregory; Church *et al*. 2001). For example, Table 2.5 illustrates for five grid box locations the range of normalised regional sea level changes resulting from thermal expansion and ocean processes simulated by seven AOGCMs. Moreover, account also needs to be taken of the long-term, non-climate related trend, which is usually associated with vertical land movements that affect relative sea level. Subsidence, due to tectonic movements, sedimentation, or human extraction of groundwater or oil, enhances relative sea-level rise. Uplift, due to post glacial isostatic rebound or tectonic processes, reduces or reverses sea-level rise. Locally observed relative sea-level change thus consists of contributions from global, regional, and local processes.

A simple approach for developing scenarios that account for variations and uncertainties in regional sea level changes was presented by Hulme (2002), who recommended considering the range of global-mean scenarios ±50% change so that impacts are understood across the range of possible change. In this approach, the detailed scenarios would be developed after the impact assessment, and the impact assessment could be reinterpreted if new scenarios emerged, as long as they fell within the range of the assessment.

Table 2.5: *Normalised sea-level change (cm/cm global sea level rise) from thermal expansion and ocean process as simulated by different AOGCMs for different "locations".*

	CGCM1	CGCM2	CSIRO	GFDL -R15	GFDL-R30	HadCM2	HadCM3
Buenos Aires	1.11	1.01	0.94	0.98	1.01	0.91	0.92
Los Angeles	1.17	1.10	1.14	0.91	0.94	1.26	1.09
Osaka	0.89	0.96	0.98	0.92	0.74	1.33	1.86
Stockholm	1.28	1.21	1.35	1.50	1.38	1.07	1.50
Sydney	1.11	1.24	1.07	1.04	0.94	1.42	1.14

CLIMsystems (2005) have developed a software tool that generates future scenarios of local sea-level change during the 21st century, accounting for contributing factors at global, regional, and local scales. Their method combines spatial patterns of sea level rise from thermal expansion and ocean process taken from AOGCM simulations with global-mean sea-level rise projections from simple climate models (e.g. MAGICC as described in Wigley 2003), through the pattern-scaling technique. Users are also required to input a value for the local sea-level trends (for example, as estimated from tide gauge data) to account for local land movements. This value is added on to the regional component, but only after subtracting an estimate of the climate-change-related portion of that trend. An advantage of a generator is that it allows rapid generation of place-based sea level scenarios accounting for various sources of uncertainty.

Storm surge scenarios. Several studies stress the importance of characterising extreme sea level events that typically have a high impact but a low probability of occurrence. In many locations, the risk of extreme sea levels is poorly defined even under present-day climatic conditions, due to sparse tide gauge networks and relatively short temporal records having a sufficiently high frequency of measurements. Where such records do exist, the trends that have been detected are highly dependent on local conditions of coastal geometry and the tracks, frequency and intensity of storms (Woodworth; Blackman 2004).

In Chapter 6, Nicholls *et al*. document several examples of recent studies that have attempted to simulate extreme water levels for the present-day and future climate at a limited number of sites. Box 6.2 describes document three approaches that are typically employed to simulate future changes in extreme water levels, which have direct analogies to the downscaling of regional climate (see above). These are summarised briefly here.

The first, statistical downscaling approach, involves the construction of statistical relationships between observed coarse scale synoptic conditions and local extreme sea levels. Scenarios of future water levels are developed by applying these relationships to coarse scale features of the future climate as simulated by global climate models. The approach assumes that relationships between coarse scale climate and local water levels remain constant over time. This assumption may not be valid if, for example, there are major shifts in storm tracks in the future.

The second, stochastic sampling approach, identifies characteristics (intensity and movement) of synoptic weather events that are responsible for extreme water levels and randomly samples from frequency distributions of these to generate a population of severe weather events. Observed surface wind and pressure fields from such events are applied to a storm surge model to simulate water levels. Changes in future conditions (e.g. based on information from high resolution climate models) are represented by altering the frequency distributions and resampling. This approach may not capture the full range of synoptic forcing, but the approach does facilitate the generation of long time series of rare events at the tail of the distribution.

The third, dynamic approach, typically involves using coarse scale boundary conditions from a global climate model simulation to drive a high resolution regional atmospheric model at grid scales of 25 or 50 km. The surface winds and pressure from the atmospheric model are then used to drive a regional hydrodynamic ocean model. The advantage of this approach is that it does not presume anything about the relationships between local water levels and coarse-scale synoptic conditions. However, it has the disadvantage of computational expense, which limits the periods of simulations and hence may not adequately capture extreme behaviour.

2.3.2.4 Regional socio-economic, technological and land use scenarios

Socio-economic scenarios

Socio-economic changes are key drivers of projected changes in future emissions and climate and are also key determinants of vulnerability, potential adaptation, and the impacts that ultimately result from future climate change. CCIAV studies typically require socio-economic scenario information at the sub-national level, whereas many scenarios are developed at the level of nations or world regions. For example, the United Kingdom "Fast Track" project group used population and GDP information downscaled to national and grid level for a series of global studies of the impacts of climate change on different sectors (Arnell; Livermore *et al*. 2004) – see Box 2.4. Since the TAR, there has been substantial development of approaches to downscaling aggregate socio-economic scenario information to smaller geographic regions, including information on qualitative storylines, population, and economic development (GDP).

Box 2.4 The importance of scenario selection in the global "fast track" studies

Scenarios applied in the "fast track" studies

As an attempt to provide consistent and comparable estimates of climate change impacts across sectors, a series of global-scale “fast track” impact assessments have been undertaken by a multi-disciplinary research team (Parry, 1999; Parry, 2001; Parry, 2004). Three sets of global assessments have been completed and provided estimates of climate change impacts under unmitigated GHGs emissions (Arnell 1999: Hulme; Mitchell *et al*. 1999: Martens; Kovats *et al*. 1999: Nicholls; Hoozemans *et al*. 1999: Parry; Rosenzweig *et al*. 1999: White; Cannell *et al*. 1999),under CO_2 stabilisation at 550 ppm and 750 (Arnell, 2002; Nicholls, 2004), and under four alternative SRES emissions scenarios (Arnell, 2004), climate and socio-economic scenarios; Levy, 2004, natural ecosystems and the terrestrial carbon sink; Arnell, 2004, global water resources; Parry, 2004, global food production; Nicholls, 2004, coastal flooding and wetland loss; (van Lieshouta, 2004). Assessments within each of these sets were based on the same climate change scenarios and assumptions about key socio-economic variables across the five key sectors: ecosystems, water, food, coast and health. This facilitated an analysis of the relative magnitude of impacts on different sectors at a global level. Sectoral assessments assuming different emissions, climate, and socio-economic futures apply the same impact models. Key features of the scenarios underlying these three sets of global assessment are summarized in Table 2.6.

The effect of scenario selection on the impact outcomes

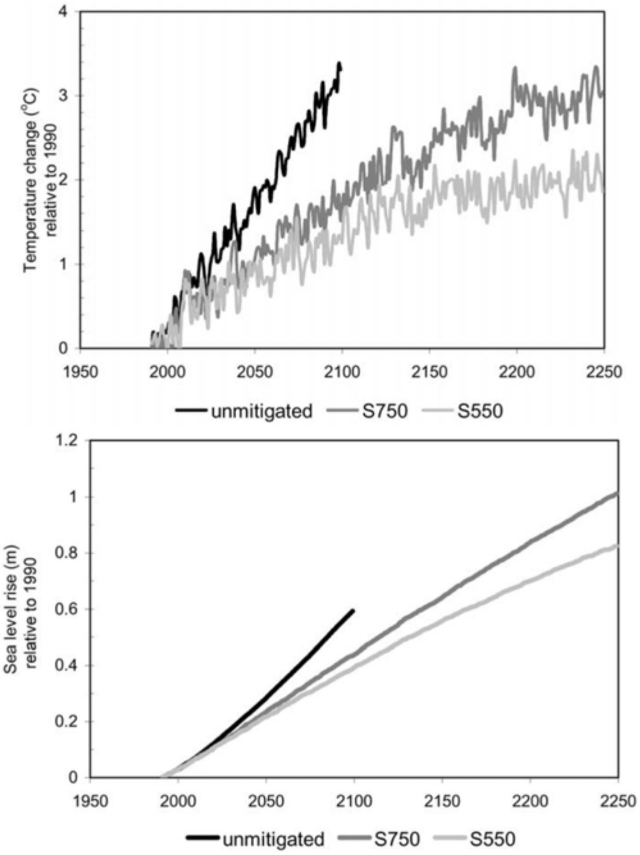
The results of the three sets of "fast track" studies were strongly affected by scenario selection. The first set of studies sought to provide comparisons of a future world with (unmitigated) climate change and a world without climate change. They concluded that net ecosystem productivity may decrease significantly in mid-century, leading to the possibility of the terrestrial carbon balance becoming negative before the end of the century. increases were estimated in the number of people living in countries with water stress, in food prices and the risk of hunger (with the most severe impacts in developing countries), in rates of wetland loss and in the number of people at risk of coastal flooding. The assessments had the advantage of being compatible and consistent, but they rely only on a single representation of future socio-economic conditions and emissions (IS92a) as well as climate projections from only one AOGCM (four ensembles from the HadCM2 model).

The second set of studies addressed the implications for the same sectors of stabilising CO_2 concentration at different levels (see Figure 2.6). Only one climate simulation was available for the 550 ppm and 750 ppm stabilisation pathways, so the effects of inter-decadal natural climate variability could not be analysed using ensembles. A single socio-economic future (IS92a) was assumed for both these scenarios and the unmitigated case. This was taken from the earlier study. Results indicated that the effect of stabilisation is to delay the 2050 temperature increase under unmitigated emissions by about 50 (750 ppm) and 100 (550 ppm) years. Stabilisation at 750 ppm has relatively little effect on the impacts of climate change on water resource stress, and on populations at risk of hunger or falciparum malaria until the 2080s. However it delays the loss of tropical forest and grassland from the 2050s to the 22nd century. Stabilisation at 550 ppm preserves the tropical forest and grassland, even by the 2230s, coastal wetland loss is slowed considerably and the risk of coastal flooding rises much more slowly than under unmitigated conditions. Water resource stress is reduced substantially, but risk of malaria and hunger are little affected. The latter two results are primarily due to the regional pattern of precipitation change under stabilisation, which does not show consistent differences from the unmitigated case. The conclusion of the study was that stabilisation at 550 ppm is necessary to avoid or significantly reduce impacts in the unmitigated case.

The third set of studies considered alternative SRES-based socio-economic futures. These have differing effects in different sectors. For instance, several non-linearities in the world food supply system were noted by Parry *et al*. (Parry; Rosenzweig *et al*. 2004). The SRES scenarios of a more globalised world (A1 and B1) experience greater reduction in yield than the scenarios of a more regionalised world (A2 and B2), and greater increases in prices and risk of hunger in poorer countries under scenarios of greater inequality (A1FI and A2). For the analysis of water resources, several alternative AOGCM projections of future climate were used alongside the standard HadCM3 set (Arnell 2004), leading to the conclusion that the impact of climate change depends least on the rate of future emissions and most on the AOGCM providing the climate scenario. Moreover, future population assumptions have a large effect on the numbers of people with changes in water stress.

Table 2.6: *Key features of scenarios underlying global scale assessments*

	Impacts of unmitigated emissions	**Impacts of stabilisation CO_2 emissions Stabilisation**	**Impacts of SRES emissions scenarios**
Emissions scenarios	IS92a (1% per increase in CO2-equivalent concentrations per year from 1990)	S750 and S550	Four SRES emissions scenarios: A1FI, A2, B1 and B2
Climate scenarios	Derived from four ensemble HadCM2 simulations and one HadCM3 simulation forced with IS92a emissions scenarios	Derived from HadCM2 experiments assuming stabilisation of CO_2 at 550 and 750 ppm; comparison with IS92a.	Derived from HadCM3 ensemble experiments (number in brackets): A1FI (1), A2 (3), B1 (1) and B2 (2)
Socio-economic scenarios	IS92a consistent GDP and population projections	IS92a consistent GDP and population projections	SRES-based socio-economic projections



Impact indicator	Unmitigated emissions	S750 emissions	S550 emissions
2020s			
Population with potential increase in water stress (millions)	338 to 623	242	175
Change in average annual number of people flooded in coastal storms (millions)	2	1	1
Change in global cereal production (million metric tonnes)	–26 to –30	–28	–24
Change in population at risk of hunger (millions)	25 to 35	50	34
Change in population at risk of falciparum malaria (millions)	147 to 171	180	211
2050s			
Population with potential increase in water stress (millions)	2209 to 3195	2108	1705
Change in average annual number of people flooded in coastal storms (millions)	20	13	10
Change in global cereal production (million metric tonnes)	–51 to –25	–27	–23
Change in population at risk of hunger (millions)	–3 to 9	7	5
Change in population at risk of falciparum malaria (millions)	197 to 258	224	220
2080s			
Population with potential increase in water stress (millions)	2831 to 3436	2925	762
Change in average annual number of people flooded in coastal storms (millions)	79 to 81	21	5
Change in global cereal production (million metric tonnes)	–105 to –73	–13	–51
Change in population at risk of hunger (millions)	69 to 91	16	43
Change in population at risk of falciparum malaria (millions)	257 to 323	174	253

Figure 2.6: *Global temperature and sea level rise projections and their socio-economic impacts under different emissions scenarios (Arnell, 2002).*

For example, the SRES scenarios have been used as a basis for developing storylines for national (Carter; Fronzek *et al*. 2004: Van Vuuren; Lucas *et al*. 2005, submitted) downscaling drivers or sub-national regions (Berkhout; Hertin *et al*. 2002: Heslop-Thomas; Bailey 2004: Shackley; Deanwood 2003: Solecki; Oliveri). The content of downscaled storylines depends on the information needed for a particular application. For example, in preparation for an impact assessment of Northern Nigeria, four sub-national storylines were developed that included qualitative demographic and economic trends, the nature of governance, policy, and social and cultural values (Nyong; Berthe *et al*. 2004).

In contrast, most regional studies in the AIACC research programme adopted a participatory, sometimes *ad hoc*, approach to socio-economic scenario development. In most cases, changes in socio-economic conditions are inferred from the examination of current trends in key socio-economic indicators and stakeholder consultation on their possible future patterns (e.g. Heslop-Thomas, 2004, vulnerability and adaptation; Pulhin, 2004, people and places}.

Approaches to downscaling quantitative population information have progressed from initial methods that were transparent and simple but produced unrealistic results in some cases, to improved methods more likely to produce credible outcomes. For example, an initial downscaling of the SRES population projections to the national level suffered from some unrealistic long-term outcomes (Gaffin; Rosenzweig *et al*. 2004a). The method used country-specific population projections from the UN as a guide to downscaling scenario information originally produced at the level of world regions. However, at that time country-specific projections were available only to 2050, so a simplifying assumption was made that beyond 2050, each country's share of the regional population would remain constant. This approach cannot take into account variations in country-specific conditions, and results for several countries displayed implausible discontinuities in growth paths beyond 2050 (Gaffin; Rosenzweig *et al*. 2004b).

Subsequent analyses have improved on this approach. Two studies have used updated country-specific projections (UN 2003) that now extend well beyond 2050 to downscale the SRES population assumptions, eliminating the problem of obvious discontinuities in population size (Grübler; *et al*. in prep.: van Vuuren; O'Neill in prep.). These approaches produce substantially different results for many countries compared to the earlier work. For example, in one of these approaches (Grübler; *et al*. in prep.), 30 countries differ by more than +/- 50% in population size in 2100 as compared to the earlier downscaling of the A1/B1 scenario, seriously questioning the validity of the post-2050 growth rates in the original downscaling. Because they use updated projections based on more recent demographic data, the revised downscalings have also improved accuracy in the base year (Grübler; *et al*. in prep.); in some countries the earlier downscaling approach produced population sizes in the year 2000 that differ by 10% or more from recent estimates.

Downscaling of SRES population assumptions to the sub-national level has also been carried out. The ATEAM project developed urbanization scenarios for Europe based on the SRES scenarios for use in an analysis of land use implications *[publication in review, more to come when available]*. A study of the impacts of sea level rise (Nicholls 2004) developed coastal population scenarios which assumed uniform sub-national growth rates in once case, and that coastal population grows at twice the national rate in another. Several studies have downscaled scenarios to the grid level (0.5° x 0.5° resolution) using the Gridded Population of the World (GPW) Version 2 data set (CIESIN 2000), assuming that population changes everywhere within a country at the same rate (Gaffin; Rosenzweig *et al*. 2004b: van Vuuren; O'Neill in prep.). This approach assumes that the share of national population residing within a given grid cell remains constant over time. A recent refinement on this approach uses observed trends in population shares at the grid level for a recent 5-year period as a basis for extrapolating changing shares into the future (Gaffin; Hachadoorian *et al*. 2005). An alternative approach uses urbanization projections for each country and downscales urban and rural population separately, with urban populations distributed spatially based on a density-driven gravity model (Grübler; *et al*. in prep.).

Downscaling approaches for GDP are also evolving. The first downscaling of the SRES GDP assumptions was developed using a linear downscaling method that applied regional growth rates uniformly to all countries within the region (Gaffin; Rosenzweig *et al*. 2004b). Two important drawbacks to this approach are that GDP is downscaled independently from population, and that it does not take into account country-specific differences in initial conditions and growth expectations. For example, this method led to implausibly high ranges of GDP across countries within regions, including unrealistically high per capita incomes by the end of the century in some countries.

Two studies have developed alternative GDP downscalings that focus on GDP per capita, rather than GDP, and that are based on convergence algorithms rather than a linear model (Van Vuuren, in prep., the consistency of; Grübler, in prep., spatially explicit}. Assumptions about rates of convergence across countries within particular regions are specified as a scenario assumption. This approach avoids implausibly high growth for rich countries in developing regions. Results reveal very large differences (for some countries an order of magnitude) with earlier work (Gaffin; Rosenzweig *et al*. 2004b). GDP scenario have also been downscaled to the grid level, either by assuming constant shares of GDP in each grid cell (Gaffin; Rosenzweig *et al*. 2004b: van Vuuren; O'Neill in prep.) or through scenario dependent sub-national algorithms (Grübler; *et al*. in prep.).

Land use scenarios

Many climate change impact studies need to account for future changes in land use and land cover. This is especially important for regional studies of agriculture and water resources (Barlage; Richards *et al*. 2002: Klöcking; *et al*. 2004), forestry (Bhadwal; Singh 2002) and ecosystems (Bennett; Carpenter *et al*. 2003: Cumming; Alcamo *et al*. 2005: Dirnbock; Dullinger *et al*. 2003: Zebisch; Wechsung *et al*. 2004), but also has a large influence on regional patterns of demography and economic activity (Geurs; van Eck 2003) and associated problems of environmental degradation (Yang; Kanae *et al*. 2003) and pollution (Bathurst; Moretti *et al*. 2005). Land use and land cover change scenarios have also been used to analyse feedbacks to the climate change (DeFries; Bounoua *et al*. 2002: Leemans; Eickhout *et al*. 2002: Maynard; Royer 2004) and the emissions of GHGs (El-Fadel; Jamali *et al*. 2002: Fearnside 2000: Sands; Leimbach 2003). Baseline data are required as a starting point for constructing land use and land cover scenarios, and some global sets were summarised in the TAR (Carter; La Rovere *et al*. 2001). These include statistical data sources such as the annual reports of the Food and Agriculture Organization (FAO 1999) and satellite-derived land cover datasets such as the high-resolution global database, DISCover (Loveland; Belward 1997). Furthermore, attempts have also been made to develop historical land use and land cover databases using proxy sources, such as maps, population-density estimates and infrastructure, to approximate land-cover patterns (Klein Goldewijk 2000: Ramankutty; Foley 1999).

The TAR concluded that IAMS were the most appropriate approach to the development of land use change scenarios. Since the TAR, however, a number of alternative modelling techniques have emerged that have been applied to land use scenario development to the extent that IAMS can no longer be considered to be the most appropriate tool for this purpose. New approaches are based on purpose-built models of land use change processes (often using a “storyline and simulation” approach Alcamo 2001) and differ from IAMs in their focus on regional to local application scales. IAMS still have an important role to play, but mostly in characterising the global conditions that constrain regional applications (van Meijl; van Rheenen *et al*. (in press)). The need to define exogenous input variables to regional scale and use scenario analyses remains a challenge (e.g. Alcamo; Kok *et al*. in press: Sands; Edmonds 2005). Regional scale methods often adopt a two-phase approach. The first phase is an assessment of aggregate quantities of land use (often driven by macro-economic processes using outputs from IAMs) that are, in the second phase, 'downscaled' using rules and model simulations. Whilst these models are based on a common approach they often, however, vary considerably in terms of their use of individual models, and can integrate regional scale economic models (Fischer; Sun 2001) with spatial allocation procedures based on rules (Rounsevell; Reginster *et al*. 2005, in press), micro-simulation with cellular automata (de Nijs; de Niet *et al*. 2004: Solecki; Oliveri 2004), linear programming models (Holman; Rounsevell *et al*. 2005a: Holman; Rounsevell *et al*. 2005b) or empirical-statistical techniques (e.g. CLUE/EURURALIS Verburg; de Koning *et al*. 1999: e.g. CLUE/EURURALIS Verburg; Soepboer *et al*. 2002). Not all land use scenario exercises have addressed the effects of climate change even though they consider time frames over which a changing climate would be important. This sometimes reflects a perceived lack of sensitivity to climate (e.g. studies on urban land use Allen; Lu 2003: Barredo; Kasanko *et al*. 2003: Barredo; Demicheli *et al*. 2004: Loukopoulos; Scholz 2004), but otherwise represents an omission within the analysis (Ahn; Plantinga *et al*. 2002: Berger; Bolte 2004).

Other methods for the construction of land use scenarios have been used in CCIAV studies. The simplest approach is to apply arbitrary changes in land use areas, e.g. + 10% forest, -10% cropland, etc., where these area changes are spatially explicit (Shackley, 2003) or not (Ott; Uhlenbrook 2004: Van Beek; Van Asch 2004: Vaze; Barnett *et al*. 2004). These approaches are, however, more similar to sensitivity analysis than to scenarios, as their feasibility, logic, drivers and processes are not usually described. However, these scenarios often reflect policy targets and concerns (van den Bergh 200?). Other studies have attempted downscaling approaches or interpretations of global scenarios to the regional scale (Arnell; Livermore *et al*. 2004), often based on simple rules. Regional economic models have also been used that are based either on General Equilibrium models (van Meijl; van Rheenen *et al*. (in press)) or input/output approaches (Fischer; Sun 2001). These approaches are limited, however, in their representation of geographic space. The storylines for land use scenario development generally have a predefined logic and dimensions (e.g. SRES), although some participatory approaches have allowed the storylines to evolve in response to stakeholder visions (e.g. Berger; Bolte 2004: Rotmans; Van Asselt *et al*. 2000); PRELUDE project (*reference to follow*). Participatory approaches are also seen as important in order to reconcile a given long-term scenario framework with the shorter-term and particular policy-driven requirements of stakeholders (Shackley; Deanwood 2003: Velázquez; Bocco *et al*. 2001). Most land use scenario assessments are based on mean trends in the socio-economic and climate change baselines, although responses to extreme weather events such as hurricane Mitch in Central America have also been assessed (Kok; Winograd 2002). Probabilistic approaches in the development of land use futures are rare, although an example has been applied to hydrological modelling (Eckhardt; Breuer *et al*. 2003).

Scenarios of future technology

The role of technology can be a key uncertainty in some scenarios. In two recent scenario exercises, the Millennium Ecosystem Assessment (MA) and the International Assessment of Agricultural Science and Technology for Development (IAASTD) new attempts have been made to develop scenarios which treat technological change as a major driver. Within the Millennium Ecosystem Assessment (MA) one of the four scenarios, called TechnoGarden, explores the "double edged sword" of technology development and use. This scenario describes a world in which the development of green technologies, aimed at managing, even engineering, ecosystems to optimize the delivery of ecosystem services, is used to deal with environmental problems. This push for a specific direction of technical change is coupled with the development of markets for a whole variety of ecosystem services and investments in human and manufactured capital, which leads to an overall improvement of certain human well-being indicators and a moderation of environmental degradation. Nevertheless, the reliance mainly on technical, engineered solutions also creates new dependencies and new solutions result in a new problems, thus taxing societies' ability to implement novel solution to emerging problems.

IAASTD aims to assess the role of knowledge development, science and technology and the direction of technical change in the agricultural sector and how these impact on the ability of countries to achieve wider developmental goals. As part of the assessment a set of scenarios are being built (to be released by mid 2007) on plausible knowledge, science and technology development pathways. The scenarios will be built within the overall framework of the four MA scenarios and also include a fifth scenario that combines different positive aspects of the MA scenarios, proposing a way forward towards reaching social and environmental sustainability.

Some land use change scenario studies have attempted to address the effect of technology (notably effects on agriculture through crop yield changes), but most studies ignore this driver. Current studies (Ewert; Rounsevell *et al*. 2005) treat technology by using simple response functions based on the observation of past trends and expert judgement about the future. Such studies have been useful in demonstrating the importance of technology in future land use change scenarios, especially the relative sensitivity of land use change to technology with respect to climate change (Rounsevell; Ewert *et al*. 2005), but the approach is often based on assumptions that are difficult to validate. Thus, future work should seek to find ways of treating technological development more appropriately. That only a few studies have tackled technology suggests an imbalance in the treatment of environmental change drivers within land use and CCIAV scenario studies. Technology and social drivers are on the whole dealt with less often than other drivers. This has important implications for the assessment of adaptation and vulnerability to climate change.

Scenarios of singular events with widespread consequences

Several types of rapid, non-linear response of the climate system to anthropogenic forcing, sometimes referred to as "surprises", have been suggested in the literature (Hulme 2003: Streets; Glantz 2000). These include a reorganisation of the thermohaline circulation, rapid deglaciation of a major ice sheet and fast changes to the carbon cycle (e.g. Stocker; Schmittner 1997). Given the large uncertainties concerning their nature or probability, few representations of such events that can be considered plausible have been applied in impact studies (hence their designation as non-scenario approaches in section 2.3.1.2, above) and none were analysed by impact assessors during the TAR. They are treated here as scenarios primarily because of their usefulness in exploring the types of impacts to be expected and level of preparedness were such events to occur.

A sudden collapse of the thermohaline circulation in the North Atlantic could cause major disruptions in regional climate over northwest Europe. In the TAR, an assessment of a set of AOGCM experiments concluded that most models projected a weakening of the THC over this century, although none showed a shut-down (near cessation) over that time period (Cubasch; Meehl *et al*. 2001). These experiments were driven by one forcing scenario (IS92a), did not include the possible effects of melt water from land-based ice sheets, and did not extend beyond 2100, leading the authors to conclude that "it is too early to say with confidence whether irreversible shut-down of the THC is likely or not, or at what threshold it might occur" (Cubasch; Meehl *et al*. 2001). The fact that other model analyses have shown a near cessation of the THC under some circumstances was taken to imply that a shut down in response to the projected range of climate change cannot be ruled out (Stocker; Clarke *et al*. 2001).

A recent model inter-comparison supports the view that freshening of surface waters during this century is expected to be much smaller than that required to produce a shutdown (Chapter 10, WG1). However the possible implications of a shutdown for global climate, which may represent conditions for next century, have been explored in "hosing experiments" with the HadCM3 AOGCM, which assume a sudden freshening (reduced salinity) in the North Atlantic (e.g. Vellinga; Wood 2002: Wood; Vellinga *et al*. 2003). One of these experiments (Wood; Vellinga *et al*. 2003) assumed a greenhouse gas forcing of the atmosphere described by the IPCC IS92a emissions scenario up to 2049, whereupon freshwater was suddenly introduced to the North Atlantic, inducing a THC shutdown. Substantial reduction of greenhouse warming occurred in the Northern Hemisphere, with a net cooling occurring mostly in the North Atlantic region. However, in general the effect of a THC shutdown on regional climate change could be to reduce greenhouse warming, but not to offset it entirely. The net effect is dependent on climate model sensitivity, the forcing scenario, and how much warming has occurred by the time of shut-down (Stocker; Clarke *et al*. 2001).

The results of THC modelling studies have been used to investigate the effects on potential ecosystem structure and function using a process-based dynamic global vegetation model (Higgins; Vellinga 2004). In earlier studies, synthetic climate scenarios of cooling over Europe were applied to investigate possible extreme impacts of a THC shutdown (Alcamo; van den Born *et al*. 1994: Klein Tank; Können 1997).

Current models indicate slow deglaciation of the Greenland or Antarctic ice sheet on timescales of a millennium or longer (Gregory; Huybrechts *et al*. 2004: Huybrechts; de Wolde 1999) for local warming of about 3 C and 10 C respectively. Based on recent observations (Scambos; Bohlander *et al*.: Thomas; Rignot *et al*.: Zwally; Abdalati *et al*.), it has been proposed that rapid deglaciation of either or both ice sheets could occur over the course of a few centuries (Hansen: Oppenheimer; Alley 2004: Vaughan). Complete disintegration of the West Antarctic Ice Sheet (WAIS) would raise sea level by about 4-6 m and could be triggered by a global mean warming of 2-4ºC (Oppenheimer; Alley 2005). An abrupt disintegration of the WAIS is considered unlikely during the 21st Century (Oppenheimer 1998: Vaughan; Spouge 2002), although forcing during the 21st century could be sufficient to lead to deglaciation in subsequent centuries. For Greenland, complete deglaciation would lead to 7 meters of sea level rise.

There are few examples of scenarios representing such abrupt sea-level changes during the 21st century. Given the poor understanding and indeterminate probability of such events, such exercises are best described as screening assessments, and the assumed changes in sea level as exploratory. One recent example, is an analysis of the potential impact of a 5m rise on the coastal zone (Nicholls; Tol *et al*. 2004). This level of change greatly exceeds all of the upper estimates described elsewhere in the literature for the current century and is hence highly improbable. However, rather than being a conventional "business-as-usual" impact assessment, this was intended as a sensitivity study to explore preparedness (Dawson 2004: Poumadère; Mays *et al*. 2004: Toth; Hizsnyik 2004), decision making (Guillerminet; Tol 2004: Lonsdale; Downing *et al*. 2004) and adaptation (Olsthoorn; van der Werff *et al*. 2004: Tol; Bohn *et al*. 2004) under a "worst case" abrupt rise in sea level.

In a second study, a scenario of rapid sea-level rise is characterised by an increase of 2.2m by 2100, relative to the 1990 mean, with the increase continuing unabated after 2100 (Arnell in press). This increase of 20mm per year represents the maximum IPCC rate (8.8mm per year) plus a contribution of 10 mm per year from the West Antarctic Ice Sheet, plus a little more to allow for decline of the Greenland Ice Sheet. Arnell (in press) also describe the potential impacts of such a scenario in Europe, based on expert assessments.

The next section characterises future conditions under the SRES scenarios, since these underpin many of the studies reported in this Report and provide a set of reference conditions for the Assessment as a whole. Subsequent sections explore applications of mitigation scenarios, since these are of increasing interest and importance for policy making, as well as other scenarios that are of relevance in CCIAV assessments.

2.3.3 SRES-based scenarios for the 21st century

The publication of the IPCC Special Report on Emissions Scenarios (SRES) (Nakićenović; Alcamo *et al*. 2000) has presented a useful starting point for impact assessors working in different parts of the world to construct a range of mutually consistent climate and non-climatic scenarios. The SRES storylines are based on short narratives of possible developments during the 21st century, which are arranged around the level of globalisation and different values. The SRES team defined four narrative storylines, labelled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways. The two digit codes (A1, B1, A2 and B2) locate scenarios in a four-quadrant chart. The vertical axis distinguishes between a more economic emphasis (A) and a more environmental and equity-orientated emphasis (B). The horizontal axis ranges from a more global (1) to a more regional (2) emphasis of governance. Because of their different socio-economic assumptions, each storyline has different levels of greenhouse gas emissions. However, all of the SRES narratives assume that no specific climate policies are implemented, and thus form a baseline against which narratives with specific mitigation and adaptation measures can be compared. The latter are described in section 2.3.4, below.

A strength of using qualitative narratives, such as those developed by SRES, is that the assumed socio-economic changes not only relate directly to climate change through the emissions scenarios, but also to other aspects, such as impacts (Carter; Fronzek *et al*. 2004: Rounsevell; Reginster *et al*. 2005, in press). Some impacts will be less or more likely in the different narratives. For example, a B1 world will use natural resources in a sustainable way and conserve biodiversity. This will certainly reduce the impacts of climate change. Thus, with such a narrative approach, it is now possible to develop scenarios that encompass the full range of socio-economic and environmental changes that could affect regions in the future in an internally-consistent way. A limitation of a global scenario framework, however, is the geographical scale. Coarse scenarios, such as SRES, derived for global scale applications are of limited value without guidelines to their application at the regional scale.

The SRES storylines formed the basis for the development of derivative quantitative scenarios using various numerical models that were presented in the TAR. Emissions scenarios were converted to projections of consequent changes in atmospheric greenhouse gas and aerosol concentrations, radiative forcing of the climate, effects on regional climate, and climatic effects on global sea level (IPCC 2001b). However, little regional detail of these projections could be included in the TAR. Some of that detail, taken from subsequent work, is presented in this report. Furthermore, the SRES framework is generic and qualitative: it does not provide descriptions of regional changes in other non-climate factors. Thus, in developing scenarios for individual sectors and regions within the SRES framework, it is still necessary both to interpret regional scale and sector-based driving factors and to quantify the effects of these drivers. The narratives facilitate an interpretation that is internally-consistent, although one that still remains subjective. The following sections describe downscaling approaches that have been adopted to achieve this consistency.

2.3.3.1 SRES-based socio-economic and technological scenarios

Socio-economic components of the SRES scenarios provide essential input to impact assessment. SRES provides this information in the form of storylines and quantitative assumptions on population, gross domestic product (GDP), and rates of technological progress, at the level of four large world regions. Two issues of importance to impact assessment are the status of these global and regional scenarios, and the development of probabilistic representations of the socio-economic scenarios and their resulting emissions.

Current status of the SRES global and regional scenarios

Since the TAR, several of the quantitative assumptions about the SRES driving forces have been re-examined. For example, updated population projections anticipate substantially less global population growth than projections made at the time SRES was in development, due to surprisingly fast declines in birth rates and, in Sub-Saharan Africa, an unexpectedly large toll taken by the AIDS epidemic. As a result, there has been a general downward shift in the full range of population size projections of about 1-2 billion (van Vuuren; O'Neill in prep.). These changes in outlook at the global level are driven primarily by the developing country regions (Asia and ALM), with the changes particularly large in the China region, Middle East and North Africa, and Sub-Saharan Africa. On balance the population assumptions used in SRES are still credible, but researchers using them should take into consideration the comparison to more recent demographic outlooks, especially in the A2 scenario which now lies above the current range of projected outcomes(van Vuuren; O'Neill in prep.). Revised versions of the SRES population assumptions have been produced that indicate that a global population size of around 12 billion in the A2 scenario is more realistic than the original assumption of about 15 billion (Grübler; *et al.* in prep.: Hilderink 2004: O'Neill 2004). Alternative interpretations of other SRES population scenarios have also produced outcomes that differ from the original assumptions (Hilderink 2004).

On economic growth, two aspects of the SRES scenarios have been examined: the consistency of assumed growth trends with recent data and projections, and the metric used to express GDP. An examination of the SRES GDP scenarios against more recent scenario literature (including 2000-2020 projections of IMF/World Bank) shows that growth assumptions for the ALM region (Africa, Latin America and Middle East) are generally higher than found in the more recent literature (van Vuuren; O'Neill in prep.). This is particularly the case for the A1 and B1 scenario. The total SRES range is also not representative of more recent low growth scenarios for this region. For other regions, the SRES scenarios are much more consistent with current literature. Given the small share of the ALM region in global GDP level, the global GDP assumptions in SRES are generally consistent with current projections.

For international comparison, economic data must be converted into a common unit, which is generally done in terms of US$ based on market exchange rates (MER). Purchasing-Power-Parity estimates (PPP), in which a correction is made for differences in price levels among countries, are considered to be a better alternative for comparison of income levels across regions and countries. Most models and economic projections, however, use MER-based estimates, partly due to a lack of consistent PPP-based data sets. The use of MER-based economic projection in SRES has been questioned (Castles; Henderson 2003), suggesting that as a result of the use of MER, the economic growth projections in SRES are inflated. In an ongoing debate, some researchers argue that PPP is indeed a better measure and that its use will lead to different scenarios of economic growth patterns and emission paths. Others argue that consistent use of either PPP or MER based numbers will lead to at most only small changes in outcomes. An overview of this debate is provided in Chapter 3 of Working Group III; it concludes that the impact on emission levels of the use of alternative GDP metrics is likely to be small (but indicating alternative positions as well).

Probabilistic representations

Since the TAR some studies have explored the possibility of probabilistic representations of the SRES scenarios. For example, probabilistic population projections conditional on each of the four SRES storylines were derived and used as the basis for developing a set of conditional probabilistic emissions projections (O'Neill 2004). Results showed that considering the uncertainty in population within storylines leads to much wider ranges of emissions within the A2 and B2 storylines than represented in SRES. Distinctions (in terms of emissions outcomes) across storylines are also blurred by including uncertainty in demographics within storylines.

A number of other studies have developed probabilistic representations of future global emissions without explicitly assigning probabilities to the socio-economic scenarios driving emissions outcomes. Many of them use the SRES scenarios as a basis even though SRES authors explicitly did not assign relative likelihoods to scenarios, In almost all cases the decision has been to treat the individual scenarios as equally likely, at least as a starting point for the analysis (Dessai; Hulme 2001: New; Hulme 2000: Wigley; Raper 2001b). In some studies (Dessai; Hulme 2001: New; Hulme 2000) this assumption was then relaxed to investigate the sensitivity of results to alternative specifications of emissions probabilities. Probabilistic representations of socio-economic scenarios have also been produced for other global scenarios such as those for the Millennium Ecosystem Assessment (O’Neill, 2005), and probabilistic greenhouse gas emissions projections have also been produced independent of SRES (Webster; Babiker *et al*. 2002).

2.3.3.2 Characterizing future adaptive capacity in SRES worlds

The SRES storylines also contain detailed narrative information which can help in the construction of other useful quantitative and qualitative scenarios, including characterizations of potential adaptive responses to climate change. These narrative descriptions have been used to produce further quantitative indicators at the sub-national and national level (e.g. Shackley; Deanwood 2003: e.g. Turnpenny; Tim O’Riordan *et al*. 2005), the European scale (e.g. Parry 2000: Rounsevell; Reginster *et al*. 2005, in press) and the global scale (e.g. Arnell 2004: e.g. Nicholls 2004).

For instance, the ATEAM project (Schröter; *et al* 2004) used SRES-based GDP and population projections to derive adaptive capacity scenarios in Europe. Determinants and their indicators of adaptive capacity are first identified through questionnaire survey. Empirical relationship between these indicators and population and GDP over 1960-2000 is then established. Scenarios of adaptive capacity are then derived from such empirical relationship and downscaled SRES-based GDP and population projections.

Nicholls(2004) interpreted the SRES storylines to estimate the exposure of human populations to coastal flooding. He used GDP per capita scenarios to estimate the future standards of coastal defences in the absence of relative sea level rise. As noted earlier, problems arise in downscaling assumptions about protection strategies from SRES macro-regions to country level. For example, as mentioned above, under the B1 marker scenario, the Pacific islands are regionally grouped with Australia and New Zealand (rather than with Asia as in the other markers) and are thus projected to experience limited growth which makes them more vulnerable to sea-level rise than under the other marker scenarios (Nicholls 2004).

Parry, 2004, effects of climate change on global food production} have estimated future risk of hunger using a food model that makes assumptions about yield changes, food demands and trade liberalisation. Two types of adaptation strategy were incorporated in the model simulations: farm-level adaptation strategies, such as changes in planting date, and application of additional fertilization and irrigation, and regional-scale adaptation, considered by modifying the yield changes derived from the production functions in developed countries to represent potential changes that require investments such as development of new cultivars and irrigation infrastructure. Other economic adjustments to the modelled yield changes are tested by a world food trade model, including increased agricultural investment, re-allocation of agricultural resources according to economic returns, and reclamation of additional arable land as a response to higher cereal prices.

The adaptive capacity of natural ecosystems (sometimes referred to as acclimation) is much more restricted than that of most human systems, and is strongly influenced by land-use change. For example, Sala (2000) used scenarios of land use change, climate and other factors to assess future threats to biodiversity in different biomes. They explicitly addressed a biome's adaptive capacity and found that the dominant factors determining biodiversity decline will be climate change in polar biomes and land-use in tropical biomes. The biodiversity of other biomes was affected by a combination of factors, each influencing vulnerability in a different way.

2.3.3.3 SRES-based land use and land cover scenarios

Future land use was estimated by most of the integrated assessment models used to characterize the SRES storylines, but estimates for any one storyline vary widely, depending on the model applied (Figure 2.7). For example, under the B2 storyline the change in the global area of grassland between 1990 and 2050 varies between –49 and +628 million ha (Mha), with the marker scenario giving a change of +167Mha (Nakicenovic; Alcamo *et al*. 2000). The integrated assessment model used to characterize the A2 marker scenario did not include land cover change, so changes under the A1 scenario were assumed to apply also to A2. Given the differences in socio-economic drivers between A1 and A2 that can affect land use change, this assumption is not appropriate. Note also that the SRES land cover scenarios do not include the effect of climate change on future land cover. This is a weakness in the internal consistency of these scenarios, especially with respect to agricultural land use where changes in crop productivity would be expected to play an important role in land use (e.g. *insert multiple references*).

In attempting to downscale from the SRES land cover scenarios for application in global ecosystem modelling, Arnell(2004) assumed that everywhere within an SRES macro region changes at the same rate, whereas, in practice, land cover change is likely to be greatest where population and population growth rates are greatest. They also found a mismatch in some of the SRES storylines and for some regions between recent trends and projected trends for cropland and forestry.

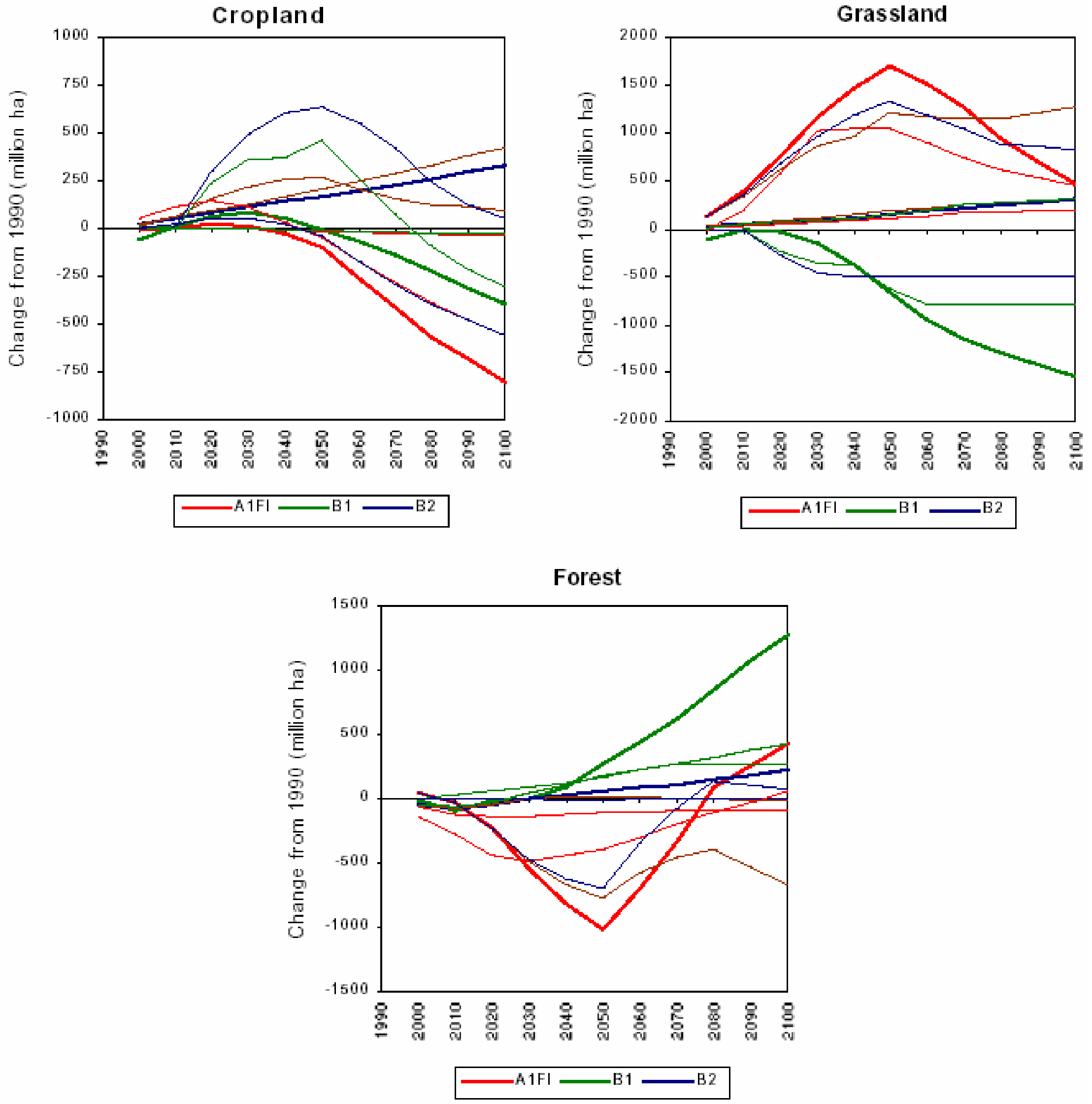


***Figure 2.7:** Global land cover changes under the SRES scenarios (after (Arnell et al. 2004).*

In a more sophisticated downscaling exercise for the ATEAM project (Rounsevell; Ewert *et al.* 2005), future agricultural land use during the 21st century was simulated at a 10 x 10 minute resolution across Europe based on an interpretation of the four SRES marker scenarios (A1FI, A2, B1, B2). The interpretation commenced with a qualitative description of the potential drivers of change that might affect European agricultural land use in the future. An assessment was then made of the total area requirement (quantity) of agricultural land use (ha) at the European scale using a simple supply/demand model. Global food demand was specified using outputs from an integrated assessment model. The quantities of agricultural areas were then spatially distributed (disaggregated) across the 10-minute European grid using spatial allocation rules. The allocation rules were scenario specific based on an interpretation of the SRES assumptions at the regional scale, specifying the location of land use change as a function of policy, political intent and/or land quality, depending on the scenario. The agricultural scenarios were also adjusted to account for increasing urbanisation (simulated separately) and the location of protected areas, both assumed to take priority over agricultural production. This analysis highlighted the potential role of non-climate change drivers in affecting future land use. Technological change, especially as it affects crop yield development, was shown to be the most important factor in determining future agricultural land use (and much more important than climate change), contributing to declines in agricultural areas of both cropland and grassland by as much as 50% by 2080 under the A1FI and A2 scenarios. The B1 and B2 scenarios had smaller changes in agricultural areas, but this assumed changes in management strategies toward more extensification, such as ‘organic’ production systems and the widespread substitution of agricultural food and fibre production by bioenergy crop production. Bioenergy crop areas were, in contrast, were based on the global scale IMAGE2.2 model.

The EuRuralis study followed a conceptually similar approach to that outlined above by Rounsevell (2005) EuRuralis combined the GTAP and IMAGE models at the global scale (van Meijl; van Rheenen *et al.* in press) to generate inputs to the CLUE-S model (Verburg; Schulp *et al.* (in press)) in the creation of regional scale land use change scenarios based on SRES. Other SRES-based studies have created downscaled land use change scenarios of forestry (Kankaanpää; Carter 2004) and agro-pastoral land use (de Chazal Submitted) using qualitative interpretations and statistical methods. Other developments in the interpretation of the SRES scenarios include the use of a pairwise comparison approach (Abildtrup; Audsley *et al.* (in press)) to ensure the internal consistency of expert judgements in the construction of agricultural economic scenarios. The pairwise comparison provided a tool for the quantification of scenario drivers and model parameters from the SRES narrative storylines, generating input parameters (prices, costs subsidies, productivity, etc.) for an agricultural land use model (Audsley; Pearn *et al.* (in press)).

All of the studies outlined above were undertaken for one geographic region only, Europe and so, it is difficult to draw general conclusions from SRES-based land use scenarios that have widespread resonance. However, certain of the scenario outcomes for Europe show strong similarities. Agricultural land abandonment is found across most of the SRES scenarios, although the declines in agricultural areas are less striking for the environmental (B) scenarios. This is not necessarily surprising given that many of the exogenous (economic) inputs to these studies were based, at least partly, on the IMAGE model. Differences exist, however, between studies in terms of both the magnitude and the location of land use change. These differences appear to reflect uncertainties in both the underlying models used in the scenario assessments and the (largely subjective) interpretation of the global SRES storylines at the regional scale (Rounsevell; Reginster *et al.* 2005, in press). This suggests that regional scale land use change models have much scope for improvement and that regional scenario developers need to refine the methodologies for interpreting regional from global narratives (Alcamo; Kok *et al.* 2005, in press).

2.3.3.4 SRES-based climate scenarios

The global mean annual temperature is the measure that has been most commonly employed by the IPCC and adopted in the international policy arena to describe future changes in global climate and its likely impacts. In the TAR, a projected range of global mean temperature change by 2100 (relative to 1990) of 1.4 to 5.8ºC was reported for the range of SRES emissions scenarios (IPCC 2001b). While this measure is adopted in some global assessments of the aggregate costs and damages of climate change (Hitz; Smith 2004), it is of little use for impact, adaptation and vulnerability studies conducted at a regional scale. These studies require more detailed regional projections of the key climate variables to which natural and human systems are exposed. They also require projections at a temporal resolution appropriate for studying impacts, usually ranging from annual down to sub-daily time scales, and encapsulating changes in variability and extreme events as well as changes in mean climate. Extensive summaries of the methods that are available for obtaining regional-scale climate scenarios were reported in the TAR (Giorgi; Hewitson *et al.*

2001: Mearns; Hulme *et al*. 2001), and procedures to assist impact assessors in applying these methods have also recently been documented (Mearns; Giorgi *et al*. 2003: Wilby; Charles *et al*. 2004).

Since publication of the TAR, a large number of simulations of the global climate response to greenhouse gas and aerosol concentrations assuming SRES emissions have been completed with coupled atmosphere-ocean general circulation models (AOGCMs). The early runs were reported in the TAR (Cubasch; Meehl *et al*. 2001) and all of these results are available from the IPCC Data Distribution Centre (DDC)[7]. Many have been employed in impact studies reported in this assessment and are summarised below. A new generation of GCMs, so-called Earth System Models (ESMs), which incorporate improved representations of climate system processes and land surface feedbacks, are now being used to simulate climate responses to the SRES scenarios as well as to a number of other emissions scenarios of potential relevance for impacts and policy. Results are summarised in Chapters 9 and 10 of the Working Group I Report, and these are compared at the end of this section with the earlier SRES-based scenarios that form the basis for many of the studies presented in this Report.

Most of the AOGCM results held at the DDC were included in a model intercomparison exercise conducted by (Ruosteenoja; Carter *et al*. 2003), which summarised results for the 32 world regions previously defined within WG II/TAR (Figure 2.8 *[Could also be a table of the regions, and then contain summary scenario data as well]*). Regional data were plotted as scatter diagrams of temperature change against precipitation change for all four seasons of the year and for three future time periods: 2011-2040, 2041-2070, and 2071-2100. Estimates of modelled natural climate variability were also derived.[8]

[Graphs summarising the information in the regional scatter diagrams to be constructed, perhaps for insertion in an Appendix to the report]

The model-simulated temperature changes were almost invariably statistically significant, i.e., they fell clearly outside the natural multi-decadal variability derived from 1000-year unforced coupled AOGCM simulations (Ruosteenoja; Carter *et al*. 2003). For precipitation, fewer modelled changes were statistically significant, especially in the earliest projection period 2010-2039. Differences in the projections given by various models were substantial, of the same order of magnitude by the end of the century as differences among the responses to separate forcing scenarios. Nevertheless, the surface air temperature increased in all regions and seasons. As described in the TAR when referring to similar regions to those shown in Figure 2.8 (Giorgi; Hewitson *et al*. 2001), most land areas warm more rapidly than the global average. The modelled warming is in excess of 40% above the global average in all high northern latitude regions and the Tibetan Plateau region in December-February (DJF) and in southern Europe, central and northern Asia and the Tibetan Plateau in June-August (JJA). Only in south Asia and southern South America in JJA and southeast Asia in DJF and JJA do the models consistently show warming less than the global average.

For precipitation, changes with both sign occurred, but an increase of regional precipitation was more common than a decrease. All models simulate higher precipitation at high latitudes in both seasons, northern mid-latitude regions and tropical Africa in DJF and enhanced monsoon precipitation for Southern and Eastern Asia in JJA. There was agreement between models that

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[7] http://ipcc-ddc.cru.uea.ac.uk/

[8] Scatter diagrams are downloadable at: http://ipcc-ddc.cru.uea.ac.uk/asres/scatter plots/scatterplots_region.html

precipitation declines in Central America, Australia, Southern Africa and southern Europe in certain seasons (Giorgi; Hewitson *et al*. 2001: Ruosteenoja; Carter *et al*. 2003).

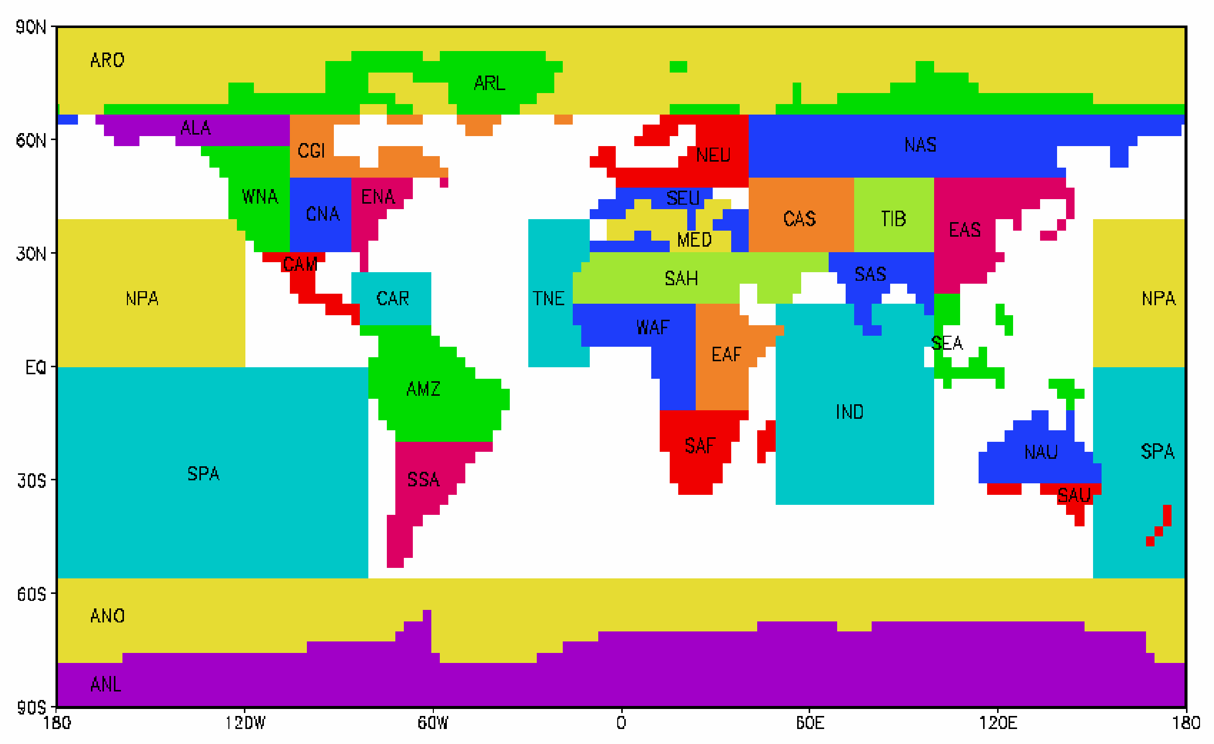

Figure 2.8: *32 world regions used to intercompare SRES-based AOGCM outputs of future seasonal temperature and precipitation change. Regions are shown on the ECHAM4 model grid (resolution 2.8 × 2.8º). Source: (Ruosteenoja et al. 2003).*

While AOGCMs are the most common source of regional climate scenarios, other methods and tools are also applied in specific CCIAV studies. Numerous regionalisation methods have been employed to obtain high resolution SRES-based climate scenarios, nearly always using low resolution GCM outputs as a starting point. For example, simulations over a European domain from more than ten different regional climate models, each using the boundary conditions from the same A2-forced GCM (Christensen; Carter *et al*. 2005), were inter-compared in impact studies of natural vegetation, agriculture and water resources in Europe (Graham; Hagemann *et al*. 2005: Olesen; Carter *et al*. 2005).

To identify appropriate methods for constructing scenarios of extreme events within an integrated modelling framework, Goodess (2003) analyzed the characteristics of drought and intense rainfall events for the nine UK regions, developed from outputs of SRES emissions scenarios forced HadCM3 experiments, the HadRM3 European experiments, and Statistical Downscaling Model (SDSM) (Wilby; Dawson *et al*. 2002) It is concluded that some form of downscaling (i.e., HadRM3 or SDSM) is preferred to using HadCM3 output directly.

In assessing potential impacts of climate change on human health in the Caribbean, SRES-based scenarios derived from GCM experiments are compared with those downscaled using SDSM (Chen; Rhoden *et al*. 2004). It is suggested that downscaling adds values over direct GCM outputs.

It should be noted that not all of the impact studies reported in this assessment employed SRES-based climate scenarios. Some have adopted scenarios based on AOGCM simulations forced by the earlier IPCC IS92a emissions scenario. These were compared with SRES-based scenarios in the TAR (Cubasch; Meehl *et al*. 2001: Giorgi; Hewitson *et al*. 2001). Others have applied projections based on equilibrium doubled-CO_2 model simulations or projections at the time of CO_2-doubling from transient model simulations. These projections are described in earlier IPCC reports (Greco; Moss *et al*. 1994: IPCC 1992: 1996b).

SRES-based projections of climate variability and extremes

Assessments of the impacts of climate change often require information on both changes in mean climate and possible changes in variability and the frequency/severity of extreme events. Projected changes in extreme weather and climate events were summarised globally in the TAR (Cubasch; Meehl *et al*. 2001), and have been updated in Chapter 11 of WG I. Examples of the types of impacts projected for such changes in extreme events are shown in Table 2.7, based on studies reported in this volume. Since extreme climate events are regional in nature, impacts too can be expected to be region-specific. The examples in Table 2.7 are designed to portray both the types of impacts that can be confidently expected, given the occurrence of extreme climate events, and the regions in which they are most likely to occur. *[To be developed in co-operation with WG I]*

Table 2.7: *Examples of impacts resulting from projected changes in extreme climate events. Columns 1 and 2 are taken from Table 11-?, Chapter 11, WG I. Likelihood scale: VL very likely (>90% probability), L likely (>66% probability). [Placeholder awaiting further development]*

Temperature related phenomena		
Change in Phenomenon	**projected changes (21st century)**	**Examples of impacts**
More warm days	VL	
Higher maxTmax	VL	
More warm nights	VL	
Higher maxTmin	L	
Longer, more intense heat waves	VL	
Fewer cold nights	??	
Warmer minTmin	VL	
Fewer cold days	??	
Warmer minTmax	??	
Fewer frost days	VL	
Reduced diurnal temperature range over most land areas	??	
Increase of heat index over land areas, heat index rises more than temperature	VL	
Moisture related phenomena		
Change in Phenomenon	**projected changes (21st century)**	**Examples of impacts**
More intense precipitation events	VL	
Longer runs of consecutive dry days	L	
More wet days per year	L	

Increased continental summer drying and associated risk of drought	L	
Tropic cyclones		
Change in Phenomenon	**projected changes (21st century)**	**Examples of impacts**
Increase in tropical cyclone peak wind intensities	L	
Increase in tropical cyclone mean and peak precipitation intensities	L	
Decreased frequency in tropical cyclones	??	
Longer mean duration of tropical cyclones	??	
Exratropical Cyclones		
Change in Phenomenon	**projected changes (21st century)**	**Examples of impacts**
Increased frequency in extra tropical cyclones		
Increased intensity in extra tropical cyclones		

Comparing TAR/SRES projections to recent SRES projections

[Section to be drafted in co-operation with WG I]

2.3.3.5 SRES-based sea level scenarios

At the global level, simple models that account for the expansion of sea water and melting/sliding of land-based ice sheets and glaciers were used in the TAR to obtain estimates of global mean sea-level rise across the SRES scenarios, yielding a range of 9-88 cm by 2100 relative to 1990 (IPCC 2001b). This range has been updated in this assessment to ???-??? cm (Chapter 10, WG I). *[To be expanded when new information is available from WG I]*.

In a global study of coastal flooding and wetland loss Nicholls (Nicholls 2004) used results from the HadCM3 AOGCM to determine global mean sea-level rise estimates for the four SRES storylines by 2025, 2055 and 2085. These were used to ensure consistency with climate scenarios derived from the same model in other parallel studies (cf. Box 2.4). The sea level estimates fall in the middle of the IPCC TAR range. As a sensitivity study, in countries experiencing coastal subsidence two subsidence scenarios were applied to obtain relative sea-level rise: a low case (15 cm/century) assumed to represent the natural subsidence, and a high case (45 cm/century) including additional human-induced subsidence due to groundwater withdrawal. Nicholls speculates that the latter may be more likely under some SRES storylines than others.

Since the TAR, there have been several attempts to provide regional sea level scenarios that are consistent with the SRES storylines for use in CCIAV assessments. For example, the United Kingdom Climate Impact Programme decided to adopt the TAR global mean sea-level rise estimates in national scenarios out to the 2080s, correcting these according to regional rates of vertical land movement due to isostatic uplift and subsidence, and acknowledging uncertainties in regional sea level rise by suggesting that users consider changes ±50% around the global range (Hulme; Jenkins *et al*. 2002). Scenarios of high water levels were also developed, by combining mean sea level changes with estimates of future storminess, using a storm surge model. However, due to the large uncertainties in future wind strength and direction, quantitative scenarios of wave height were not provided.

Sea level scenarios up to 2100 under the four SRES scenarios were estimated for the Finnish coast by Johansson (Johansson; Kahma *et al*. 2004). Their calculations accounted for global mean sea level, local land uplift and estimates of the water balance of the Baltic Sea, and the uncertainties of each of these were estimated. Water levels in the Baltic Sea are known to be related to the North Atlantic Oscillation (NAO) (Johansson, 2003; Woolf, 2003) and projections of the future behaviour of the NAO were analysed from AOGCM simulations. Relative sea level has been declining along the entire Finnish coast since the last glaciation, due to isostatic adjustment, but the new scenarios indicate a reversal of this trend in the Gulf of Finland, and a reduced sea level fall in the Gulf of Bothnia, where land uplift is stronger (Figure 2.9). Scenarios of monthly high water levels were also constructed by extrapolating the 20th century trends of increasing variability, though the authors acknowledge that this procedure probably overestimates the return periods of these events (Johansson; Kahma *et al*. 2004).

Similar scenario plots to those shown in Figure 2.9, but based on the regional pattern of sea level change from AOGCM simulations, can be produced for the SRES scenarios using a scenario generator (CLIMsystems 2005). This uses pattern-scaling techniques to convert estimates of regional sea level response to IS92a forcing from multiple AOGCM simulations into sea level scenarios based on SRES forcing. Such scenarios have been used to assess impacts and adaptation in the Pacific Islands (Tao; Yokozawa *et al*. 2004).

2.3.3.6 SRES-based projections of CO_2 and other atmospheric components

Projections of atmospheric composition are often needed to account for effects of air pollution that are concurrent with climate changes. Apart from CO_2 concentration (discussed below), scenarios of atmospheric composition need to be regional or local in scope to account for large spatial variations in the concentration and impacts of these different species. However, the IPCC has tended to offer only global-scale summaries for SRES-based conditions (e.g. for surface ozone concentrations in Prather; Ehhalt *et al*. 2001). Regional scenarios do exist for some, but these are generally produced on a case-by-case basis (e.g., Mayerhofer; de Vries *et al*. 2002) for air pollution), and are seldom SRES-based since they are usually prepared independently of the climate change issue, for example, in connection with other international initiatives and protocols on air pollution, water resources and desertification. One example where the SRES scenarios have been downscaled to country level for sulphur and nitrogen deposition and for ground-level ozone concentrations and exposure is in Finland (Laurila; Tuovinen *et al*. 2004: Syri; Fronzek *et al*. 2004).

Carbon dioxide concentration is commonly required as a direct input to models of plant growth, since it can affect both the growth and water use of many plants. CO_2 is well mixed in the atmosphere, so concentrations at a single observing site will usually suffice to represent global conditions. Model projections of global CO_2 concentration were presented in the TAR for the SRES emissions scenarios (Prentice; Farquhar *et al*. 2001). They exhibit large uncertainties in projections for a given emissions scenario, related to uncertainties in the carbon cycle.

2.3.3.7 Integrating SRES-based scenarios

The widespread adoption of SRES-based scenarios in studies reported in this Report is an implicit acknowledgement of the desirability of seeking consistency in scenario application across different studies and regions. Moreover, an increasing number of studies have made special efforts at integration across all the SRES-based scenarios they developed, including accounting for interactions between the scenarios.

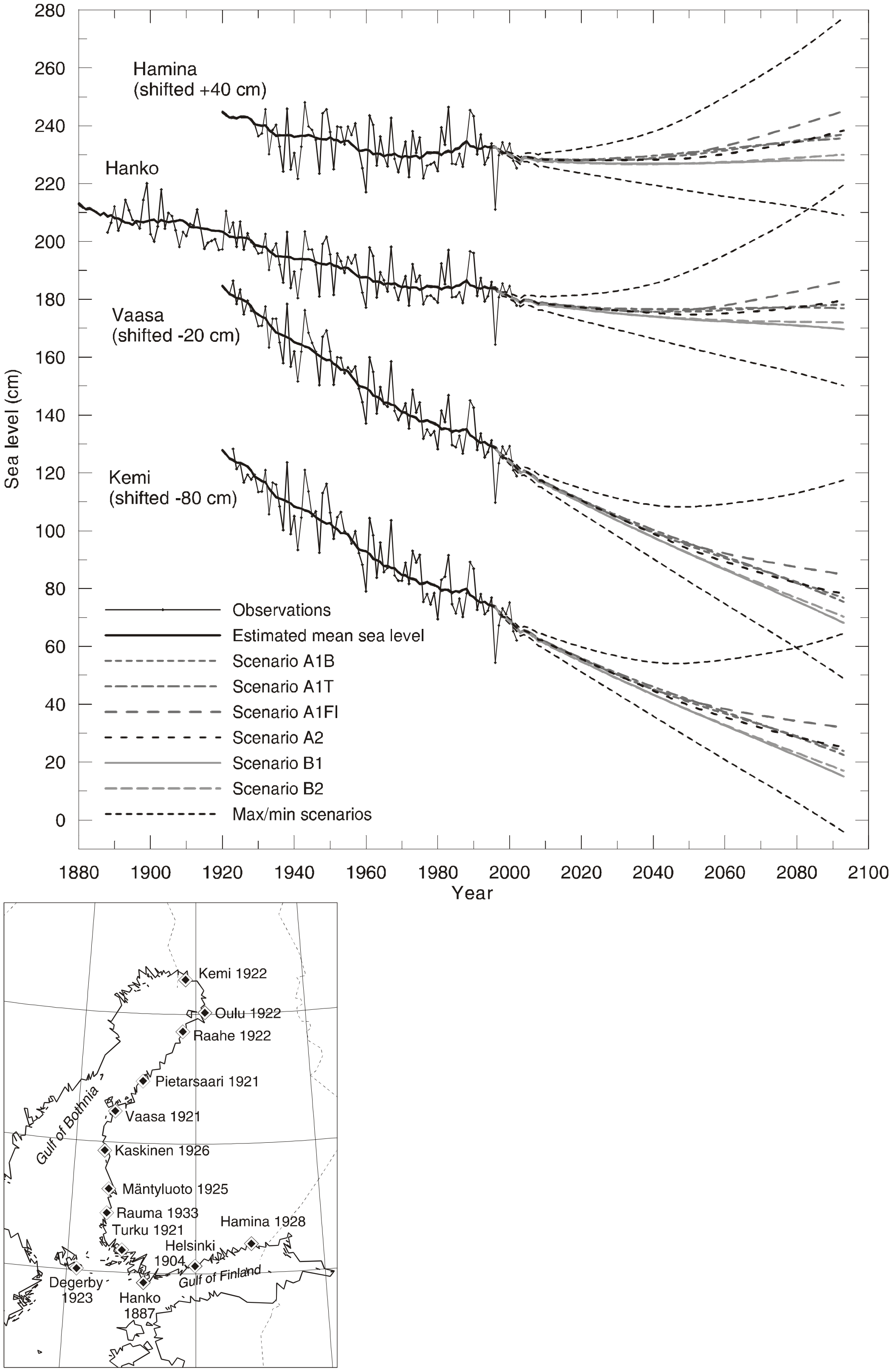

Figure 2.9: SRES-based scenarios of relative mean sea level at selected tide gauges on the Finnish coast (see inset map). The vertical scale is for Hanko, other stations have been shifted for clarity. [Inset map to be redrawn]. Source: Johansson et al. 2004.

For instance, at global scale, SRES-based downscaled socio-economic projections (Arnell; Livermore *et al*. 2004) and climate scenarios were applied in the "fast track" assessment (see Box 2.4).

At a regional scale, the European ATEAM project developed multiple scenarios for the main global change drivers (socio-economic factors, atmospheric CO_2 concentration, nitrogen deposition, climate factors, and land use), based on interpretations of the global IPCC SRES storylines B1, B2, A1FI and A (Schröter; *et al*. 2005). The scenarios were at a 10'x10' latitude/longitude grid resolution, and for time slices ending in 2020, 2050, 2080, relative to baseline conditions in 1990. Four AOGCMs were used to simulate plausible changes in European climate and from 16 combinations of storylines and AOGCMs, seven scenarios were selected for interpretation: B1, B2, A1FI, and A2 calculated with the HadCM3 GCM (providing variation across storylines), and A2 calculated additionally with the CGCM2, CSIRO2 and NCAR-PCM GCMs (variation across climate models). A set of future land use scenarios with the same spatial scale was developed based on the climatic and socio-economic scenarios (see section 2.3.3.3). Scenarios were subsequently applied in combination as inputs to ecosystem models for agricultural and bioenergy crops, forest productivity, natural vegetation, water resources, forest fire, species distribution, and soil carbon (Schröter; *et al*. 2005).

Nationally, scenarios of socioeconomic development (Kaivo-oja; Luukkanen *et al*. 2004), climate (Jylhä; Tuomenvirta *et al*. 2004), sea level (Johansson; Kahma *et al*. 2004), surface ozone exposure (Laurila; Tuovinen *et al*. 2004), and sulphur and nitrogen deposition (Syri; Fronzek *et al*. 2004) were developed for Finland in the FINSKEN project, based on the SRES driving factors as an integrating framework (Carter; Fronzek *et al*. 2004). Outputs from AOGCMs served an important integrating role in the development of the FINSKEN scenarios. They were applied in estimating the joint effects of climate change and emissions on sulphur and nitrogen deposition (Syri; Fronzek *et al*. 2004), taking results from the AIR-CLIM project which used AOGCM results as inputs to the EMEP acid deposition model (Mayerhofer; de Vries *et al*. 2002). Scenarios of temperature change based on AOGCM outputs scaled to represent the SRES emissions scenarios in the European ACACIA project (Parry 2000) were also applied directly with SRES emissions to the EMEP photochemical model to estimate the effects of temperature and emissions on ozone exposure (Laurila; Tuovinen *et al*. 2004). SRES-forced AOGCMs were used directly in developing the FINSKEN climate scenarios, as well as being examined for indications of possible changes in the North Atlantic Oscillation, which influenced the sea level scenarios developed for the Finnish coast (Johansson; Kahma *et al*. 2004).

2.3.4 Stabilisation/mitigation scenarios

Mitigation scenarios (also known as climate intervention or climate policy scenarios) are defined, as in TAR WG III (Morita; Robinson *et al*. 2001), as scenarios that "(1) include explicit policies and/or measures, the primary goal of which is to reduce GHG emissions (e.g., carbon tax) and/or (2) mention no climate policies and/or measures, but assume temporal changes in GHG emission sources or drivers required to achieve particular climate targets (e.g., GHG emission levels, GHG concentration levels, temperature increase or sea level rise limits)." Impact assessment for mitigation scenarios is important because it provides crucial information for weighing tradeoffs between the potential costs of mitigation and the impacts of climate change. The fact that impact assessment may not be sufficiently complete or reliable to support cost benefit analysis of climate change issue (Yohe 2004) does not reduce its importance. It is still essential in order to characterize risks associated with various levels and rates of climate change and therefore inform policy regarding both mitigation and adaptation (Corfee-Morlot; Höhne 2003: Jones 2003).

2.3.4.1 Types of mitigation/stabilization scenarios

A wide variety of mitigation scenarios have been developed (see Chapter 3 of Working Group 3) that differ in three principal ways: their degree of comprehensiveness, whether they take a forward or inverse approach to scenario development, and whether they are deterministic or probabilistic. Comprehensiveness is an especially important consideration for CCIAV studies. Some mitigation scenarios are strictly biophysical, limited to descriptions of future emissions, atmospheric composition, and climate change, with no storylines and no information about socio-economic and technological drivers or the mitigation activities required to achieve emissions paths (e.g. Enting; Wigley *et al*. 1994: Wigley; Richels *et al*. 1996) and AR4 WGI chapter. The majority of mitigation scenarios focus on economic and technological aspects of emissions reductions required to meet particular mitigation goals, but do not evaluate impacts associated with resulting concentration and climate change EMF-21 references to come; (Morita; Robinson *et al*. 2001). Another category of studies takes climate change projections based on mitigation scenarios as a starting point, and evaluates resulting impacts. Studies of this kind undertaken since the TAR are discussed in the next section.

Mitigation scenarios also differ in whether they take a forward approach exploring the consequences of potential policies for emissions, climate change, or impacts, or whether they take an inverse approach of exploring mitigation strategies that would be required to meet specified climate change goals. Stabilization scenarios make up an important sub-set inverse scenarios, describing futures in which emissions reductions are undertaken so that greenhouse gas concentrations or global average temperature change do not exceed a prescribed limit. Since the TAR, stabilization scenarios have been developed that are more comprehensive in their incorporation of multiple gases and aerosols (O'Neill; Oppenheimer 2004: Wigley In press-a) and AR4 WG1 chapter.

While most mitigation scenarios are deterministic, several studies have developed probabilistic approaches. One method begins with probabilistic assumptions about driving forces and about model uncertainties, and then produces uncertainty distributions for outcomes such as global average temperature change (Webster 2003) or climate change in particular geographic regions (Dessai; Hulme 2001) assuming a particular policy is implemented. Another approach begins with hypothetical goals for future emissions or concentrations, and produces uncertainty distributions for climate change outcomes without specifying policies explicitly (Mastrandrea; Schneider 2004: Wigley in press-b).

2.3.4.2 Climate change information for mitigation scenarios

Simple climate models have been used to explore the climate change implications of stabilization scenarios. Figure 2.10 shows increases in global mean temperature resulting from stabilization of the atmospheric CO_2 concentration at a range of levels

Relatively few AOGCM runs have been completed that are forced with stabilization scenarios, and only a small number have been applied directly in impact assessments (see next section). Some new simulations are reported by Working Group I *[include brief discussion from WG I Chapter 10]*. However, although they are non-intervention scenarios, some of the SRES scenarios closely resemble mitigation scenarios because they assume policies that promote emissions reduction for reasons other than climate change. These similarities have been analysed by (Swart; Mitchell *et al*. 2002) who suggested that, in the absence of climate model projections based directly on stabilization scenarios, some projections based on SRES emissions scenarios could be used a surrogates.[9] For instance, the radiative forcing associated with stabilization at 750 ppm is very similar to that associated with the A1B scenario. Other suggestions for surrogate scenarios are given in Table 2.8 (Swart; Mitchell *et al*. 2002) also point out that there is no surrogate in the SRES scenarios for stabilization at 450 ppm, which is one of the stabilization levels often considered in policy analyses.

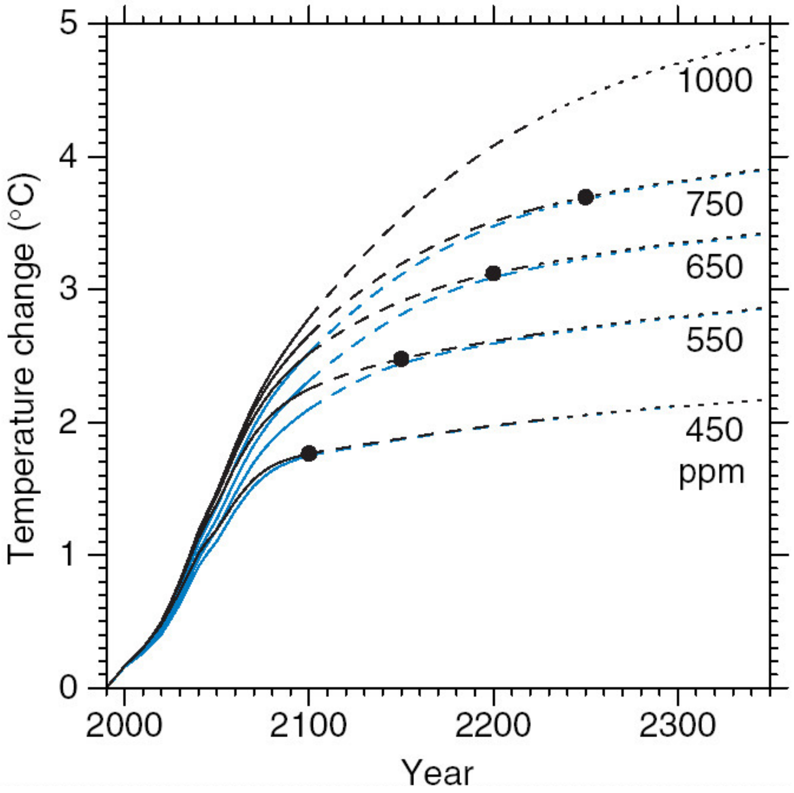

Figure 2.10: *[Placeholder. Will be replaced with profiles from recent simulations, e.g. from Washington meeting, January 2005] Projected global mean temperature changes when the concentration of CO_2 is stabilized using a simple climate model. For comparison, results with earlier profiles are also shown in blue (S1000 not available). The results are ensemble means produced by a simple climate model tuned to seven AOGCMs. The baseline scenario is scenario A1B, this is specified only to 2100. After 2100, the emissions of gases other than CO_2 are assumed to remain constant at their A1B 2100 values. The projections are labelled according to the level of CO_2 stabilization (in ppm). The broken lines after 2100 indicate increased uncertainty in the simple climate model results beyond 2100. The black dots indicate the time of CO_2 stabilization. Source: (Cubasch et al. 2001).*

The surrogate scenario approach means that it is possible to use regional climate information from

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[9] These are reasonable approximations bearing in mind the uncertainty ranges of emissions scenarios and the fact that AOGCM experiments are not expected to lead to significantly different results for small differences in greenhouse gas concentrations (e.g. below 50 ppm) and associated radiative forcing (Swart, R., J. Mitchell, T. Morita, and S. Raper, 2002: Stabilisation scenarios for climate impact assessment. *Global environmental change*, **12,** 155-165..

selected runs with SRES emissions scenarios as a surrogate for stabilization runs in impact assessments. Table 2.8 offers a guide for selecting climate projections, although projections of global mean temperature from individual AOGCMs would need to be plotted on a case-by-case basis to verify whether these approximations hold.

Application of mitigation/stabilization scenarios in impact and adaptation assessment
Mitigation scenarios have been applied to assessments of impacts and adaptation in a variety of ways. Some assessments use only climate change components of mitigation scenarios; some use socio-economic information as well, drawn either from the same scenario that generated the climate change or from other sources; and in some cases no explicit mitigation scenarios are used at all to draw conclusions on impacts associated with mitigation scenarios.

Table 2.8: *The six SRES illustrative scenarios and the stabilization scenarios (parts per million CO_2) they most resemble (based on Swart et al. 2002).*

SRES illustrative scenario	**Description of emissions**	**Surrogate stabilization scenario**
A1FI	High end of SRES range	Does not stabilize
A1B	Intermediate case	750 ppm
A1T	Intermediate/low case	650 ppm
A2	High case	Does not stabilize
B1	Low end of SRES range	550 ppm
B2	Intermediate/low case	650 ppm

For example, one approach is to identify levels or rates of climate change that could lead to particular impacts, and then analyze the emissions and concentration paths that would avoid these outcomes. Some work has focused on threshold-type impacts to physical and ecological systems and concluded that multi-gas stabilization pathways that delay emissions reductions and/or overshoot their final target increase the likelihood of triggering impacts that might be considered “dangerous” (O'Neill 2004). Other analyses have estimated the probability that a given increase in global average temperature change will lead to impacts that could be considered dangerous (Mastrandrea; Schneider 2004: Wigley In press-a) based on authors' interpretations of assessments of the impact literature such as the "reasons for concern" in the TAR (Smith; H.-J *et al*. 2001).

A second approach is to compile results from the literature on impacts associated with various levels of climate change (Hitz; Smith 2004). One of the strengths of this approach is that it makes use of a wide range of impact studies, can differentiate impacts by sector, and can identify levels of climate change that could lead to adverse impacts across a wide range of regions and sectors. At the same time, the individual studies on which it draws are based on different socio-economic scenarios, assumptions about adaptation and sectoral interaction, and climate change scenarios, which limits their comparability. For example, most impact assessments reviewed were based on GCM output ranging from equilibrium 2xCO2 runs to time slices from transient runs.

Other studies have carried out global impact assessments for a single set of scenario assumptions, although often information on different components of the scenarios are taken from different sources. Nicholls (2004) assess coastal flooding and loss of coastal wetlands that could result from long term (beyond 2100) sea level rise. They combine climate change projections from the HadCM2 model based on the S750 and S550 CO_2 stabilization scenarios with socio-economic information from the IS92a reference scenario. Parry(2001) and Arnell(2002) combine the same sets of information to estimate global impacts on natural vegetation, water resources, crop yield and food security, and malaria. The same scenarios have also been applied within a probabilistic framework to estimate by how much stabilization could delay the timing of upgrading work needed to protect London against a 1 in 1000 storm surge event (Hall; Reeder *et al*. 2004). One difficulty encountered in interpreting the results of these studies (e.g. for water resources and food security) relates to their reliance on climate and sea level scenarios based on single stabilization simulations from the HadCM2 model. Not only are model uncertainties unrepresented, as projections from only one model were applied, but additional uncertainties due to natural climate variability (especially in precipitation) could not be represented in this analysis, which adopted single rather than ensemble projections. The long-term effect of stabilization on regional climate was therefore obscured by inter-decadal natural variability.

Some studies draw conclusions on impacts associated with mitigation scenarios without using mitigation scenarios at all. In another part of their study designed to highlight the relative importance of adaptation and mitigation, (Nicholls; Lowe 2004) combine information from various SRES scenarios to infer impacts resulting from paths to stabilization. They use GCM output driven by the SRES B2 and B1 scenarios as surrogates for stabilization scenarios for 550 and 650 ppm CO_2, respectively. They then use socio-economic assumptions from 4 different SRES scenarios in combination with these two climate change projections to produce "SRES stabilization experiments". Results highlight that while mitigation leads to reduced impacts in all scenarios, socio-economic assumptions play a large role in determining the vulnerability of populations to coastal impacts. In particular, the A2 world is the most vulnerable, due to its large population and relatively slow economic development, regardless of the mitigation policy.

Similarly, Leemans(2004) assess ecosystem impacts of SRES scenarios in order to draw conclusions about impacts associated with mitigation scenarios that might produce the same climate change outcomes. Using the IMAGE model (IMAGE-team 2001a: 2001b), they describe impacts resulting from 1.0, 2.0, and 3.0ºC warming by 2100. One shortcoming of this approach is that it does not provide an assessment of rates of change less than 1ºC over 100 years, which falls outside the range of SRES scenario results. This is particularly important since the study finds substantial ecosystem impacts even with 1ºC of warming.

2.3.5 Insights gained by application of new scenarios

Different storyline interpretations can result in significant differences in scenario outcomes. For example, the introduction of alternative SRES socio-economic scenarios in a multi-sector global impact assessment had a greater effect on the outcomes than the alternative climate scenarios implied by SRES on their own. The land use scenarios developed for the ATEAM project described above (Rounsevell; Reginster *et al*. 2005, in press) demonstrate the importance of assumptions about technological development for future agricultural land use in Europe. If technology continues to progress at current rates, the area of agricultural land would need to decline substantially. Such declines will not occur if there is a correspondingly large increase in the demand for agricultural goods, or if political decisions are taken either to reduce crop productivity through policies that encourage extensification or to accept widespread overproduction. It seems likely that continued urban expansion, recreational use and forest land use could take up at least some of the surplus land, and there would be opportunities for the substitution of food production by energy production through the widespread cultivation of bioenergy crops (Rounsevell; Reginster *et al*. 2005, in press).

2.4 Future directions

[This section is still being developed.]

It is clear from the preceding discussion that climate change impact, adaptation and vulnerability (CCIAV) assessment has moved far beyond its early status as a speculative, narrowly defined academic curiosity. Climate change is already underway, and the natural environment and human societies are having to adapt to its consequences. Policy makers need to know how best to respond, and this places a suite of demands on CCIAV analysts to provide:

- Good quality information on what impacts are occurring now;
- Reliable estimates of impacts to be expected under plausible changes in climate;
- Early warning of potentially alarming or irreversible impacts;
- Quantification of different risks and opportunities associated with a changing climate;
- Effective approaches for identifying and evaluating adaptation measures and strategies;
- Credible methods of costing different outcomes and response measures;
- An adequate basis to compare and prioritise alternative response measures

To meet these demands, future research efforts need to address a set of fundamental scientific, technical, and information gaps. These include:

- *Internally-consistent stabilisation scenarios.* This refers to the construction of socio-economic and technological scenarios that account for the costs and other spin-off effects of mitigation actions designed to stabilise greenhouse gas emissions. At present, these feedbacks are not considered in most exercises.
- *Consistent approaches in relation to scenarios in other assessments.* Climate change is only one issue of many that concern policy makers. There is an increasing need for mainstreaming of climate-related scenarios into scenarios widely accepted and used by other international bodies (e.g., FAO, WHO, World Bank, OECD). The interchange of ideas and information between the different research communities will have obvious strong benefits in terms of scenario quality, usage and acceptance.
- *New approaches for reconciling scale issues. One of these is* the nesting of scenarios at different scales to create a set of multi-scale scenarios, an approach that is already being investigated in ongoing international projects such as the Millennium Ecosystem Assessment.
- *Effective communication of research results to policy makers. For example, new visualisation techniques can be quite effective in portraying alternative futures for non-specialists.*
- *Cross-sectoral assessment*s. Limited by data and technical complexity, most CCIAV assessments have so far focused on single sector. However, impacts of climate change on one sector will have implications, directly and/or indirectly, for others. Therefore, studies focusing on one sector in isolation may not capture the full extent of the risks or benefits from climate change. To be more policy relevant, future analyses need to account for the interactions between different sectors, particularly at national level (e.g. Desanker; Zulu *et al*. forthcoming: West; Gawith 2005).
- *Use of traditional knowledge (versus modern/formal science).* It is widely acknowledged that traditional knowledge of local communities represents an important, yet currently largely under-used resource for CCIAV (e.g. Huntington; Fox 2005, in press). Empirical knowledge from past experience in dealing with climate-related natural disasters such as droughts and floods (Desanker; Zulu *et al*. forthcoming), health crises (Wandiga; Opondo *et al*. 2005) as well as longer-term trends in mean conditions (Huntington; Fox 2005, in press: McCarthy; Long Martello 2005, in press) can be particularly helpful in understanding the coping strategies and adaptive capacity of vulnerable communities.

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