CLIMATE CHANGE VULNERABILITY ASSESSMENTS: AN EVOLUTION OF CONCEPTUAL THINKING

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Abstract. Vulnerability is an emerging concept for climate science and policy. Over the past decade, efforts to assess vulnerability to climate change triggered a process of theory development and assessment practice, which is reflected in the reports of the Intergovernmental Panel on Climate Change (IPCC). This paper reviews the historical development of the conceptual ideas underpinning assessments of vulnerability to climate change. We distinguish climate impact assessment, first- and second-generation vulnerability assessment, and adaptation policy assessment. The different generations of assessments are described by means of a conceptual framework that defines key concepts of the assessment and their analytical relationships. The purpose of this conceptual framework is two-fold: first, to present a consistent visual glossary of the main concepts underlying the IPCC approach to vulnerability and its assessment; second, to show the evolution of vulnerability assessments. This evolution is characterized by the progressive inclusion of non-climatic determinants of vulnerability to climate change, including adaptive capacity, and the shift from estimating expected damages to attempting to reduce them. We hope that this paper improves the understanding of the main approaches to climate change vulnerability assessment and their evolution, not only within the climate change community but also among researchers from other scientific communities, who are sometimes puzzled by the unfamiliar use of technical terms in the context of climate change.

1. Introduction

The last two decades have witnessed extensive research on potential and observed impacts of climate change on all kinds of natural and social systems, as reviewed in McCarthy et al. (2001). This research has been conducted to advance scientific knowledge and to support the formulation and implementation of policies that limit adverse impacts of climate change and variability on environmental and human systems.

This paper reviews the evolution of approaches for assessing vulnerability to climate change. We distinguish four prototypical assessment stages that address different research and policy questions. Conceptual framework diagrams show the main concepts applied in each stage and their analytical relationships. The purpose of this paper is two-fold. First, we present the prevailing understanding of the climate change community in general, and as presented in the IPCC in particular, on key concepts related to vulnerability and adaptation to climate change, and on their analytical relationships. Second, by presenting four stages of vulnerability

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assessments we sketch the development of the underlying theory over time. In so doing we aim at facilitating the understanding of the diversity of valid approaches to climate change vulnerability assessment, both within the climate change community and other scientific communities, thus improving the basis for interdisciplinary work.

In a seminal paper on integrated assessments, Rothman and Robinson (1997) have presented a "*conceptual framework for considering integrated assessments*". Their framework identifies eight attributes for characterizing integrated assessments and uses them to illustrate the evolution of integrated assessments. This evolution is reflected in the following trends:

- From linear to more complex chains of analysis,
- From non-adaptive to perfectly adaptive to realistically adaptive agents,
- From simplistic to sophisticated to pluralistic consideration of alternative developing paths,
- From strictly quantitative to quantitative and qualitative analyses,
- From science-driven to policy-driven assessments, and
- From analyses that dictate users to those that involve those users in the actual assessment process.

Recognizing the importance of these characterizations for climate change assessments, the present paper extends the discussion in Rothman and Robinson (1997) in several ways. First, we concentrate on assessments of vulnerability to anthropogenic climate change, a phenomenon characterized by its distinct spatial and temporal scales, scientific uncertainties, and policy context. Second, we illustrate the different assessment stages by presenting a series of diagrams that define key concepts of the assessment and their analytical relationships.

The development of the conceptual framework presented in this paper was motivated by the involvement of its authors in several activities aimed at integrating adaptation to climate change with current management activities in climate-sensitive sectors, notably public health and disaster risk management. Earlier versions were presented at a UNDP Expert Group Meeting on "Integrating Disaster Reduction and Adaptation to Climate Change" (Füssel and Klein, 2002) and at the 2002 Berlin Conference on the Human Dimensions of Global Environmental Change (Füssel, 2004).

We would like to emphasize from the outset that this paper focuses on the evolution of *climate change* vulnerability assessments, in particular as reviewed by the Intergovernmental Panel on Climate Change (IPCC). We are aware of the long history of vulnerability assessments developed in other contexts, such as food security, livelihoods, natural disasters, and risk management in general. Social geography, political ecology, and other disciplines have contributed crucial knowledge and experience to the assessment of societies' socio-economic vulnerability to climate change. The major concepts of vulnerability, and the contexts within which they were developed, are briefly reviewed in Section 2.2. However, it is beyond the scope of this paper to discuss in detail the evolution of vulnerability assessments outside the context of climate change and variability.

The remainder of this paper is organized as follows. Section 2 presents the context of climate change vulnerability assessments. Section 3 sketches the evolution of climate change vulnerability assessments by presenting conceptual frameworks for four different assessment stages; and Section 4 concludes this paper.

2. The Context of Climate Change Vulnerability Assessments

Assessments of the vulnerability to climate change are aimed at informing the development of policies that reduce the risks associated with climate change. In this section, we lay the foundation for this paper by presenting the main response options for climate policy and their respective information needs (Section 2.1), introducing different schools for conceptualizing the term 'vulnerability' (Section 2.2), and discussing different interpretations of the term 'climate impacts' (Section 2.3).

2.1. MITIGATION AND ADAPTATION POLICY

The two fundamental response options to the risks posed by anthropogenic climate change are *mitigation* of climate change and *adaptation* to climate change. Mitigation refers to limiting global climate change through reducing the emissions of greenhouse gases (GHGs) and enhancing their sinks. Adaptation primarily aims at moderating the adverse effects of unavoided climate change through a wide range of actions that are targeted at the vulnerable system. (It may also include taking action to seize new opportunities brought about by climate change.)

Table I summarizes the key differences between mitigation and adaptation policy. Owing to the major differences in the typical temporal and spatial scales

TABLE I
Characteristics of mitigation and adaptation

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

at which mitigation and adaptation take place and in their respective information needs, mitigation and adaptation policies are formulated largely independent of each other. This separation is also reflected in the structure of the IPCC, where mitigation is addressed by Working Group III, whereas the assessment of adaptation lies within the responsibility of Working Group II.

Mitigation has traditionally received much greater attention than adaptation in the climate change community, both from a scientific and from a policy perspective. Important reasons for the focus on mitigation are, first of all, that mitigating climate change helps to reduce impacts on all climate-sensitive systems, whereas the potential of adaptation measures is limited for many systems. It is, for instance, difficult to conceive how some of the Pacific small island nations could successfully adapt to substantial levels of sea-level rise. Second, reducing GHG emissions applies the polluter-pays principle whereas the need for adaptation measures will be greatest in developing countries, which have contributed relatively little to climate change. Third, GHG emission reductions are relatively easy to monitor quantitatively, both in terms of their absolute amount and as deviation from an established baseline. It is much more difficult to measure the effectiveness of adaptation in terms of impacts avoided, or to ensure that international assistance to facilitate adaptation would be fully additional to existing development aid budgets.

In addition to the need for mitigation there are also convincing arguments for a more comprehensive consideration of adaptation as a response measure to climate change. First of all, given the amount of past GHG emissions and the inertia of the climate system, we are already bound to some level of climate change, which can no longer be prevented even by the most ambitious emission reductions. Second, the effect of emission reductions takes several decades to fully manifest, whereas most adaptation measures have more immediate benefits. Third, adaptations can be effectively implemented on a local or regional scale such that their efficacy is less dependent on the actions of others, whereas mitigation of climate change requires international cooperation. Fourth, most adaptations to climate change also reduce the risks associated with current climate variability, which is a significant hazard in many world regions. The increasing interest in adaptation to climate change is reflected in the evolution of the theory and practice of climate change vulnerability assessments.

Effective adaptation to climate change is contingent on the availability of two important prerequisites: information on what to adapt to and how to adapt, and resources to implement the adaptation measures. The *collection of information* about the vulnerable system and the stressors that it is exposed to (in terms of scientific research, data collection, or model experiments), and the *transfer of resources* to vulnerable societies (in terms of financial means, technologies, or expertise) in order to help them to prepare for and cope with unavoided impacts of climate change are thus necessary elements of a comprehensive climate policy. These measures may either be categorized as actions that facilitate adaptation or as separate response options.

2.2. SCHOOLS OF VULNERABILITY ASSESSMENT

The term 'vulnerability' is used in many different ways by various research communities, such as those concerned with secure livelihoods, food security, natural hazards, disaster risk management, public health, global environmental change, and climate change. Already more than 20 years ago, Timmermann (1981) posited that "*vulnerability is a term of such broad use as to be almost useless for careful description at the present, except as a rhetorical indicator of areas of greatest concern*". Liverman (1990) noted that "*[vulnerability] has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk*". We could easily add exposure, sensitivity, coping capacity, and criticality to this list.

Important conceptual and semantic ambiguities include the following questions:

– whether vulnerability is the starting point, an intermediate element, or the outcome of an assessment;
– whether it should be defined in relation to an external stressor such as climate change, or in relation to an undesirable outcome such as famine;
– whether it is an inherent property of a system or contingent upon a specific scenario of external stresses and internal responses; and
– whether it is a static or a dynamic concept.

Despite this diversity, three main models for conceptualizing and assessing vulnerability can be distinguished. The *risk – hazard framework* is characteristic for the technical literature on risk and disaster management. It conceptualizes vulnerability as the dose – response relationship between an exogenous hazard to a system and its adverse effects (UNDHA, 1993; Dilley and Boudreau, 2001; Downing and Patwardhan, 2003). This notion of vulnerability corresponds most closely to 'sensitivity' in IPCC terminology and in our conceptual framework (see Section 3.3). The *social constructivist framework* prevails in political economy and human geography. It regards (social) vulnerability as an *a priori* condition of a household or a community that is determined by socio-economic and political factors (Dow, 1992; Blaikie et al., 1994; Adger and Kelly, 1999). Pertinent studies suggest a causal structure that concentrates on the differential abilities of communities to cope with external stress. Vulnerability according to this view, seen as the socio-economic causes of differential sensitivity and exposure, corresponds closely to the 'non-climatic factors' in our framework.

The glossary of the most recent IPCC Assessment Report (Houghton et al., 2001; McCarthy et al., 2001) defines vulnerability (to climate change) as follows.

Vulnerability: *The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.*

Vulnerability, according to the IPCC definition, is an integrated measure of the expected magnitude of adverse effects to a system caused by a given level of certain external stressors. This definition represents a third school of thought, which is most prominent in global change and climate change research. Vulnerability, according to this school, includes an external dimension, which is represented here by the 'exposure' of a system to climate variations, as well as an internal dimension, which comprises its 'sensitivity' and its 'adaptive capacity' to these stressors. However, since the inclusion of '*or*' in the first part of the definition seems to indicate a lingering persistence of the view that external shocks and inherent coping ability are alternative definitions of vulnerability rather than co-factors, connecting these co-factors with '*and*' would be more appropriate (Brooke, 2002). Another prominent example of such an integrated (or 'synthetic') framework is the 'hazards of place' model, which aims to integrate biophysical and social determinants of vulnerability (Cutter, 1996).

Misunderstandings caused by different conceptualizations of vulnerability can be largely avoided by using qualifying terms (Brooks, 2003; Downing and Patwardhan, 2003; Füssel, 2004). The IPCC definition of vulnerability, for instance, may be expanded into "integrated vulnerability [of a particular system over a specified time horizon] to anthropogenic climate change."

For more detailed reviews of the conceptualization of vulnerability in climate change research, the reader is referred to Adger (1999), Kelly and Adger (2000), Olmos (2001), Downing et al. (2001), Brooks (2003), Downing and Patwardhan (2003), O'Brien et al. (2004a), and Füssel (2005). Publications that discuss the meaning and the use of the concept of 'vulnerability' in general include Timmermann (1981), Liverman (1990), Cutter (1996), Kasperson and Kasperson (2001), UNEP (2002), Ford (2002), Turner et al. (2003), and Prowse (2003). References of case studies that assess vulnerability and adaptation to current climate variability and vulnerability in the context of sustainable livelihoods can be found in Moss et al. (2001) and O'Brien et al. (2004a), respectively.

2.3. A TERMINOLOGY OF CLIMATE IMPACTS

Estimates of the impacts caused by future climate change are contingent on assumptions about concurrent socio-economic developments. The comparability of these estimates is often hampered because different studies have used different assumptions, including on the type and level of adaptation measures implemented. In

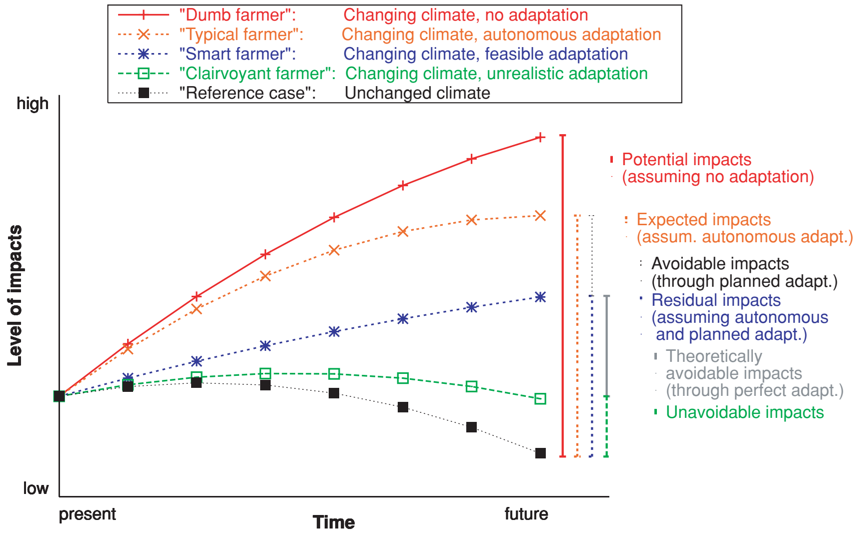

Figure 1. Different conceptualizations of climate impacts and adaptation. The individual trajectories show the combined impacts of natural climate variability and anthropogenic climate change. The bars on the right-hand side, in contrast, refer to the impacts of anthropogenic climate change only.

this section, we present a terminology for climate change impacts that distinguishes several levels of adaptation.

Figure 1 depicts hypothetical trajectories for the level of climate-related impacts (caused by anthropogenic climate change as well as natural variability) on a climate-sensitive system. The lowest trajectory denotes the (unrealistic) reference case of an undisturbed climate where variations in the level of impacts over time are solely caused by changes in non-climatic factors. The illustrative trajectory shows an initial increase in climate-related impacts (e.g., due to population growth) followed by a substantial decrease later (e.g., due to economic development). The other trajectories present the impacts associated with a single climate change scenario for four different assumptions regarding adaptation. They include (in descending order of impacts) the 'dumb farmer', who does not react to changing climate conditions at all; the 'typical farmer', who adjusts management practices in reaction to persistent climate changes only; the 'smart farmer', who uses available information on expected climate conditions to adjust to them proactively; and the 'clairvoyant farmer', who has perfect foresight of future climate conditions and faces no restrictions in implementing adaptation measures. Of course, the metaphorical names used to characterize the different assumptions on adaptive behaviour can be applied to any impacted agent. We employ these names because they are frequently used in the pertinent literature (Rothman and Robinson, 1997; Schneider, 1997). The bars on the right-hand side of Figure 1 illustrate the corresponding interpretations of the term '(climate) impacts', ranging from 'potential impacts' (assuming no adaptation) to 'unavoidable impacts' (assuming perfect adaptation). We will come back to this figure in Section 3 because the different assumptions on adaptation and the associated understanding of '(climate) impacts' can be related to different stages of climate change vulnerability assessments distinguished there.

3. Evolution of Climate Change Vulnerability Assessments

In this section, we sketch the evolution of the conceptual framework for climate change vulnerability assessments. Section 3.1 introduces the four prototypical stages of assessment distinguished here, Section 3.2 explains the diagrams used to illustrate each assessment stage, and the four subsequent sections discusses these assessment stages in more detail.

3.1. OVERVIEW

Assessments of vulnerability to climate change are conducted in a variety of contexts, and for a diverse group of stakeholders motivated by rather different concerns.

In light of the fundamental response options to climate change, three major decision contexts can be distinguished:

1. Specification of long-term targets for the *mitigation* of global climate change.
2. Identification of particularly vulnerable regions and/or groups in society to prioritize *resource allocation* for research and for adaptation (both internationally and nationally).
3. Recommendation of *adaptation* measures for specific regions and sectors.

These three decision contexts have rather different information needs in terms of the relevant spatio-temporal scales, the consideration of non-climatic stressors and factors, the treatment of uncertainty, and the importance of normative valuations. Assessments addressing the first, second, and third policy goal are denoted in this paper as 'impact assessment', (first- and second-generation) 'vulnerability assessment', and 'adaptation policy assessment', respectively. These four assessment types are subsumed under the term 'climate change vulnerability assessment'.

Despite the multitude of climate change vulnerability assessments that have been conducted for many different sectors and regions, certain trends can be observed. Detection of these trends is facilitated by the exceptional circumstance that the complete body of scientific knowledge on anthropogenic climate change, associated impacts, and potential response mechanisms is regularly synthesized by the IPCC. The preface of the WG II contribution to the IPCC Third Assessment Report highlights the following differences compared to earlier WG II assessments (McCarthy et al., 2001, p. ix):

– Efforts to address a number of cross-cutting issues, such as sustainable development, equity, and scientific uncertainties.

– The emergence of changes in climate extremes and in climate variability as key determinants of future impacts and vulnerability.
– Increasing emphasis on the many interactions of climate change with other stresses on the environment and human populations.
– The expanded analysis on the value of adaptation measures to diminish the risk of damage from future climate change and from present climate variability alike.

The IPCC reports reveal that vulnerability assessments show clear trends towards interdisciplinary analyses of the potential consequences of climate change; towards the integration of impact and adaptation assessments; and towards the integration of climate change with other stresses and concerns. These trends correspond to changing stakeholder needs from science-driven assessments that estimate potential climate impacts (in order to inform mitigation policy) to policy-driven assessments that recommend specific adaptation measures (in order to inform adaptation policy). As such, the evolution of climate change vulnerability assessments is largely consistent with the evolution of integrated assessments in other fields, as characterized by Rothman and Robinson (1997).

Burton et al. (2002), in broad agreement with Smit et al. (1999), points out that adaptation assessments can serve two distinct purposes. 'Type 1' adaptation research is carried out as part of a climate impact assessment by providing aggregate estimates to what extent feasible adaptation might reduce adverse impacts of climate change. 'Type 2' adaptation research, in contrast, contributes directly to adaptation policy development by identifying which adaptation policies are needed, and how they can best be developed, applied, and funded. For a more detailed discussion of methodological issues concerning climate adaptation assessments, the reader is referred to Dowlatabadi (1995), Rothman and Robinson (1997), Klein and MacIver (1999), Klein et al. (1999), Smit et al. (1999), and Burton et al. (2002).

Table II summarizes key characteristics of the four stages of climate change vulnerability assessment distinguished in this paper. We present this table here primarily as a reference point for the remainder of this paper. Individual entries are discussed later in the context of the respective assessment stage.

We note explicitly that the four assessment stages presented here should be regarded as prototypes of assessments reported in the pertinent literature rather than as distinct categories. Actual climate change assessments may well combine features from more than one stage. In addition, it is important to highlight that the four assessment stages presented here should *not* be interpreted as a sequence in which all but the final stage have become obsolete. The most appropriate assessment approach for a specific climate-sensitive sector and/or region depends on the research or policy questions addressed; the urgency of the threat; the geographical and temporal scope of the analysis; the reliability of future climate impact projections; the level of previous knowledge; and the availability of data, expertise, and other resources.

TABLE II
Characteristic properties of four different stages of climate change vulnerability assessment

	Impact assessment	Vulnerability assessment: First generation	Vulnerability assessment: Second generation	Adaptation policy assessment
Main policy focus	Mitigation policy	Mitigation policy	Resource allocation	Adaptation policy
Analytical approach	Positive	Mainly positive	Mainly positive	Normative
Main result	Potential impacts	Pre-adaptation vulnerability	Post-adaptation vulnerability	Recommended adaptation strategy
Time horizon	Long-term	Long-term	Mid- to long-term	Short- to long-term
Spatial scale	National to global	National to global	Local to global	Local to national
Consideration of climate variability, non-climatic factors, and adaptation	Little	Partial	Full	Full
Consideration of uncertainty	Little	Partial	Partial	Extensive
Integration of natural and social sciences	Low	Low to medium	Medium to high	High
Degree of stakeholder involvement	Low	Low	Medium	High
Illustrative research question	What are potential biophysical impacts of climate change?	Which socio-economic impacts are likely to result from climate change?	What is the vulnerability to climate change, considering feasible adaptations?	Which adaptations are recommended for reducing vulnerability to climate change and variability?

3.2. INTRODUCTION OF THE CONCEPTUAL FRAMEWORK

We illustrate the approach towards each of the four stages of vulnerability assessment by a staged series of 'box-and-arrow' diagrams. These diagrams are intended to be as generic as possible, although some adjustments may have to be made when applying them to particular impact domains. The framework for an adaptation policy assessment presented here was recently used as the basis for developing more specific frameworks for four groups of climate-sensitive diseases (Füssel et al., 2005).

Vulnerability assessments of climate change combine natural and social science perspectives. These two disciplines follow different approaches in the study of human – nature system interactions. The natural sciences tend to apply a physical-flows view, which focusses on the flow of matter and energy between system components. The social sciences tend to apply an actor system view, which emphasizes the flow of information and the relationship between different factors that determines social decision-making. The different views of the human – nature system have important implications for the visual representation of the considered system. The primary goal of system-dynamics diagrams, as applied in the natural sciences, is to clarify the behaviour of complex systems, whereas influence diagrams (and the social science models based upon them) are developed for helping people to make decisions. These two types of diagrams have been characterized as follows:

> Despite their superficial similarities, there are important differences between influence diagrams and the system-dynamics notation [. . .] First, the two notations interpret the nodes and arrows very differently. In system dynamics, nodes represent stocks, sources, and sinks of conserved quantities, such as materials, water, money, or numbers of humans or other species. The arrows represent flows of these quantities [. . .] Influences, on the other hand, do not represent material flows – they represent knowledge and beliefs, about how the value of variables affects the value or probability distributions on other variables, which may reflect knowledge on material flows, or of other evidential relationships. [. . .] (Morgan and Henrion, 1990, Section 10.7)

Both influence diagrams and system-dynamics diagrams are relevant in the context of climate change. The 'integrated assessment framework' diagram developed by the IPCC (IPCC, 2001, Fig. SPM-1), for instance, combines both aspects. The same holds for the diagrams used to illustrate our conceptual framework. The key concepts represented in these diagrams (the 'boxes') include flow variables (e.g., emissions) and state variables (e.g., concentrations), complex probabilistic properties of a system (e.g., climate variability), spatiotemporal events (e.g., exposure), human actions (e.g., adaptation), and dose – response relationships between different elements (e.g., sensitivity). Figure 2 presents the graphical elements used in these diagrams. The only distinction made between different types of concepts is between human actions (boxes with rounded corners) and other concepts (rectangular boxes). Different borders indicate whether a specific concept is usually assessed at the global level, at the level of the investigated vulnerable system, or at various levels. Two types of shading are used to highlight the starting points and end points of an assessment. The diversity within the elements of the framework gives rise to a substantial diversity in the relationships between them. We use four different types of arrows to distinguish physical flows, the effects of human actions, general functional relationships, and the flow of information. To distinguish the different types of boxes and arrows enables a more detailed representation of the analytical relationships captured in the framework. Nevertheless, we hope that the main features of each assessment stage are still comprehensible without concentrating on the details.

We conclude this section by noting that any conceptual model highlights some aspects of the system under consideration at the expense of other aspects. Important issues that are *not* explicitly addressed in either our framework or our diagrams are

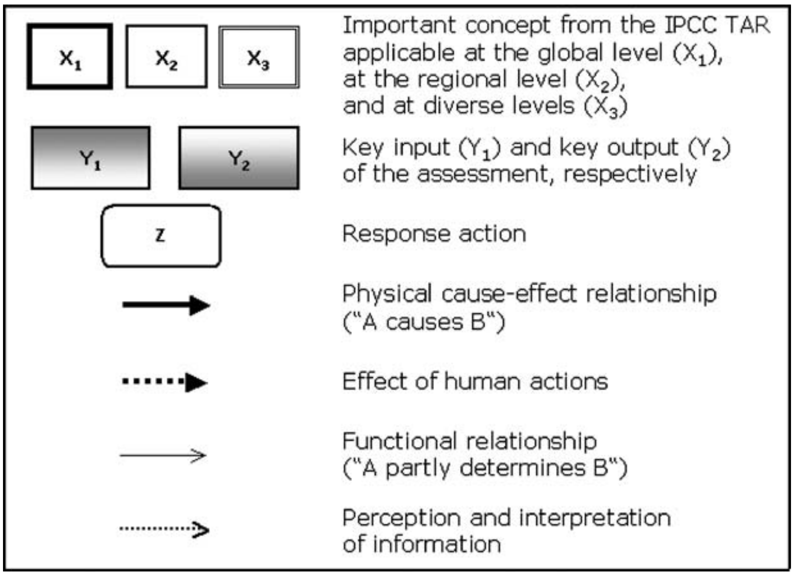

Figure 2. Legend to the conceptual framework diagrams.

the temporal dimension and dynamical aspects of the system under consideration, the nature of cross-scale relationships, the level of uncertainty associated with different elements of the framework, and the actual process of policy-making in a multi-actor context.

3.3. IMPACT ASSESSMENT

Impact assessments evaluate the potential effects of one or several climate change scenarios on one or more impact domains, and compare them to a hypothetical constant climate scenario. In so doing they aim to contribute to the identification of "*[levels of] greenhouse gas concentrations [...] that would prevent dangerous anthropogenic interference with the climate system*", referred to by Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC, United Nations General Assembly, 1992).

Figure 3 depicts the main concepts considered in an impact assessment and their relationships. The assessment starts from scenarios of either **emissions** or atmospheric **concentrations** of greenhouse gases (and aerosol precursors) such as the often assumed 2 × CO_2 case. (Global integrated assessments may start even earlier in the cause – effect chain, by looking at the underlying driving forces leading to *emissions*.) Climate models translate these scenarios into projections for future anthropogenic **climate change**.

The climate change community, in large part because of its intense co-operation within the IPCC, is developing a common terminology, although definitions are still

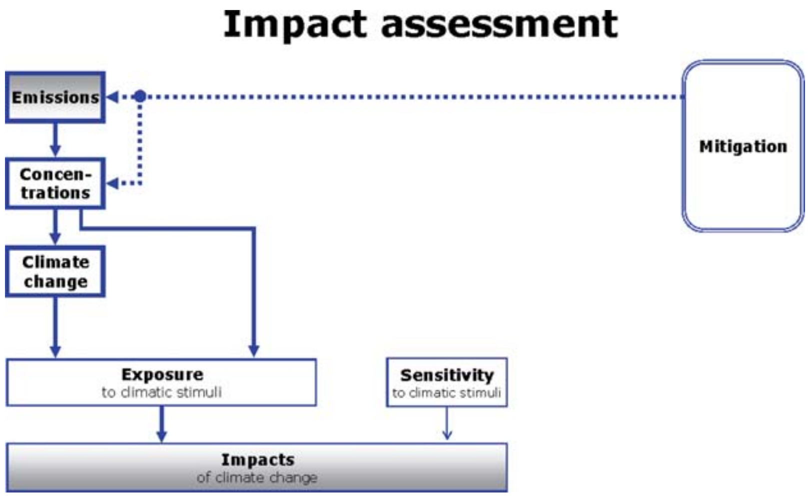

Figure 3. Conceptual framework for a (climate) impact assessment.

being debated. The definitions of key terms in the latest IPCC glossary (Houghton et al., 2001; McCarthy et al., 2001) are provided in this chapter in separate, indented paragraphs, whenever available. In the description of a conceptual framework diagram, **bold** font indicates the first mention of the name of a specific box in the text whereas *italics* are used for further occurrences.

> **Climate change:** *A statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). [. . .]*

> **Exposure:** *The nature and degree to which a system is exposed to significant climatic variations.*

The **exposure** of a system to climate stimuli depends on the level of global *climate change* and, due to the spatial heterogeneity of anthropogenic climate change, on the system's location. Climate is a multi-dimensional phenomenon that exhibits variations on various spatiotemporal scales. Burton (1997) suggests a hierarchy of weather and climate phenomena (denoted as type 1, 2, and 3 variables) to distinguish between single climate variables (such as local temperature), specific weather events (such as a convective storm), and long-term processes (such as anthropogenic climate change). Which of these aspects are included in the *exposure* definition of a particular vulnerability assessment depends on its specific circumstances. Most climate impact assessments have focussed on long-term changes in average climate conditions (such as annual mean temperature, precipitation, and sea-level rise) because these results are most readily available from climate models.

The arrow from *concentrations* to *exposure* in the diagram indicates that some systems are directly affected by changes in atmospheric composition. Well-known examples include the direct effect of carbon dioxide on plant physiology and the combination of local air pollution and high temperatures in causing respiratory diseases in humans. To be exact, the text in the *exposure* box should thus read "Exposure to climatic stimuli *and atmospheric trace gases*".

> **Sensitivity:** *The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. [...] The effect may be direct [...] or indirect [...]*

> **Impacts:** *Consequences of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential and residual impacts. [...]*

The **sensitivity** of a system denotes the (generally multi-factorial and dynamic) dose – response relationship between its *exposure* to climatic stimuli and the resulting **impacts**. The terms *potential impacts* and *residual impacts* are used to distinguish impact estimates between assessments that do *not* consider adaptation (i.e., where *sensitivity* is assumed to be unaffected by climate change) and those that do consider adaptation (see Figure 1 for a graphical illustration).

The bold borders around the boxes for *emissions* and *concentrations* of greenhouse gases and for the level of *climate change* indicate that these concepts are applicable at the global level. In contrast, the *exposure* and the *sensitivity* to climatic stimuli as well as the resulting *impacts* are only relevant at the level of the systems (or 'exposure units') subject to analysis, which is indicated by the thin borders.

It is interesting to note that the IPCC definitions for *exposure* and *impacts* are not fully consistent. Whereas the former includes all climatic variations, the latter only considers those aspects that are due to climate *change*. Climate science does not presently provide tools that can sharply distinguish climate variability according to natural and anthropogenic causes. This distinction, however, is fundamental to international climate policy. For example, only adaptations to anthropogenic climate change would be eligible for funding through the mechanisms of the UNFCCC and the Kyoto Protocol (Klein, 2002).

Impact assessments as understood here and conducted until the early half of the 1990s do not explicitly address adaptation, thereby implementing the 'dumb farmer' assumption (see Section 2.3). Their use for policy formulation is limited to raising awareness of the potential scale and magnitude of climate change impacts and to longer-term climate impacts where adaptation is difficult. Examples include many ecological studies as well as country studies conducted within, for instance, the United States Country Studies Program (USCSP). The research project on *Climate Change, Climatic Variability and Agriculture in Europe: An Integrated Assessment* (CLIVARA, Downing et al., 2000) also was a classical regional climate impact assessment. Selected other references are Monserud et al. (1993), Leemans and van den Born (1994), Kwadijk and Middelkoop (1994), Nicholls and Leatherman (1995), Rosenzweig and Parry (1994), Martens et al. (1995), and Martens et al. (1997). Impact assessments are also typical for many integrated assessment models of global climate change that determine spatially referenced projections for the effects of different emission scenarios on various impact domains, mostly in biogeophysical units. Examples include CLIMPACTS (Kenny et al., 1995), IMAGE (Alcamo et al., 1998), MIASMA (Martens, 1998), and ICLIPS (Füssel and van Minnen, 2001; Toth et al., 2002; Füssel, 2003).

3.4. FIRST-GENERATION VULNERABILITY ASSESSMENT

A (climate) vulnerability assessment is an extension of a (climate) impact assessment. We distinguish between two generations of (climate) vulnerability assessments. The step from climate impact assessment to *first-generation* vulnerability assessment is characterized primarily by the evaluation of climate impacts in terms of their relevance for society and by the consideration of potential adaptation. The main novelty of *second-generation* vulnerability assessments is the more thorough assessment of the adaptive capacity of people, thus shifting the focus from potential to feasible adaptation.

Figure 4 depicts the framework for a first-generation vulnerability assessment. Compared to Figure 3, a number of components have been added.

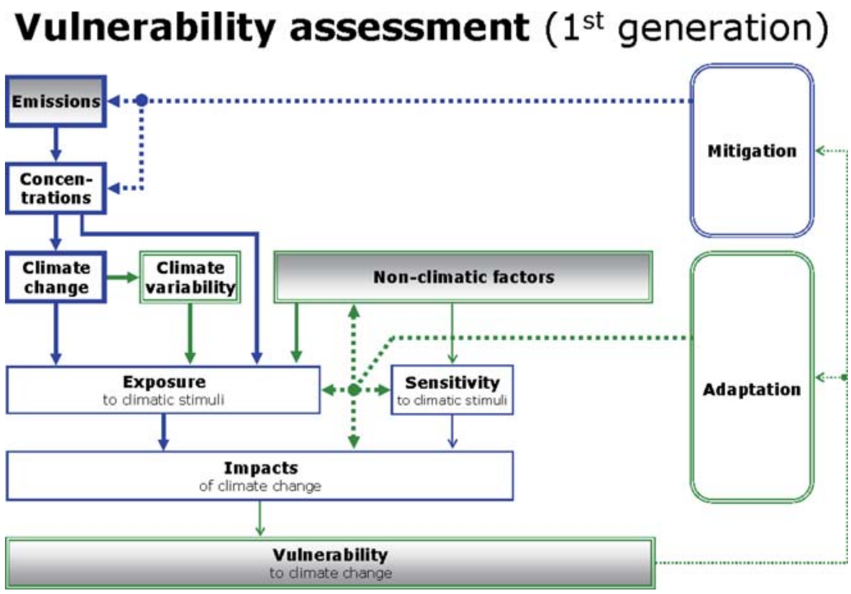

Figure 4. Conceptual framework for a first-generation vulnerability assessment.

> **Climate variability:** *Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).*

Climate variability constitutes an important component of a system's *exposure* to climatic stimuli. Global *climate change* will be superimposed on, and will substantially affect, existing *climate variability*, including the frequency, intensity, and location of extreme events. However, consideration of these effects in model-based impact assessments has been limited to date due to disagreement between different climate models on future changes in climate variability. A notable exception to this rule concerns the intensity of precipitation events, where the vast majority of climate simulations suggest an increase of heavy rains in a warming world (Cubasch et al., 2001).

Vulnerability assessments tend to focus on the vulnerable system and the multiple stresses that may threaten it rather than on the multiple effects of a particular stress factor such as climate change (Ribot, 1995). Therefore, they rely heavily on the availability of consistent scenarios for the different stressors, in particular when they are causally related to each other. The latest set of IPCC emission scenarios, the so-called SRES scenarios (Nakicenovic and Swart, 2000), are an important step forward to this end. These scenarios aim at being consistent in terms of emissions and non-climate drivers, in particular demographic and economic development. However, the spatial resolution of the SRES scenarios, which distinguish only four world regions, is generally insufficient for climate change vulnerability assessment. The importance of consistent multi-dimensional scenarios is also acknowledged in other advanced vulnerability assessments. The most prominent example is the Millennium Ecosystem Assessment, a global effort to analyze on a global, regional, and local scale the state of ecosystems, their capacity to provide goods and services, the multiple stresses that they are facing, and the potential for human actions to protect ecosystem goods and services by moderating these stresses (Ahmed and Reid, 2002). One of the four working groups of the Millennium Ecosystem Assessment is exclusively concerned with the development of consistent scenarios for a comprehensive set of driving forces (Gewin, 2002).

Non-climatic factors comprise a wide range of environmental, economic, social, demographic, technological, and political factors. We prefer the neutral term 'non-climatic factors' over 'non-climatic stressors' or 'non-climatic risk factors' because these factors may have beneficial as well as adverse effects. *Non-climatic factors* can affect the *sensitivity* of a system to climatic stimuli as well as its *exposure*. For instance, a household or a community that relocates for reasons not related to climate change will change its *exposure* to climatic stimuli. The distinction between changes in *sensitivity* and changes in *exposure* is not always straightforward for processes that affect the extent or spatial structure of the exposure unit. Consider the vulnerability to flooding of a country that experiences significant internal migration from the highlands into the flood plains. This migration changes the *exposure* of certain population groups to flooding events. Aggregated to the country level, however, the effects of migration represent changes in the *sensitivity* of the population to flooding events.

Vulnerability to climate change, as conceptualized by the IPCC, is a broader concept than potential *impacts* of climate change, as determined in climate impact assessments. Generally speaking, vulnerability assessments tend to include additional factors that increase their relevance for decision-makers. This is achieved by a more comprehensive representation of the main stressors affecting a system, including non-climatic stressors, and consideration of the socio-economic factors that determine the differential potential of communities to adapt to changing conditions. Vulnerability assessments also include a (subjective) evaluation of the magnitude and distribution of projected effects as to their desirability and importance. *Climate impacts* can generally be described quantitatively by changes in biophysical indicators (e.g., the primary productivity of an ecosystem) or in socio-economic indicators (e.g., the revenues from ski tourism in an alpine region). In contrast, no agreed metric exists to quantitatively describe the *vulnerability* of an ecosystem or a ski resort to climate change. Several authors have argued that vulnerability is a relative measure rather than something that can be expressed in absolute terms (e.g., Downing et al., 2001).

The arrow that points from *impacts* to *vulnerability* is different from most of the other arrows. This thin arrow indicates that the potential *impacts* of climate change on a particular system (in concert with its *adaptive capacity*, see Section 3.5) determine the *vulnerability* of that system to climate change. However, it does not suggest that impacts cause vulnerability. We note explicitly that the direction of causation shown in Figure 4 would be different if vulnerability to climate change were defined according to the first or second school of thought, as discussed in Section 2.2.

Vulnerability to climate change is assessed on different scales, with somewhat different policy objectives (Downing et al., 2001). Cross-scale comparisons of vulnerability have revealed that even if the overall vulnerability of a country to climate change is low, certain subgroups of the population may still be strongly affected (see, e.g., O'Brien et al., 2004c). This characteristic is reflected by the double border around the 'vulnerability box'.

Recognition of the *vulnerability* of valued systems to climate change is likely to trigger policy responses at different levels. This potential for human response is indicated by the dashed arrows originating from *vulnerability*.

Mitigation: *An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.*

Mitigation of climate change refers to actions that limit the level and rate of climate change. The two basic mitigation options are the reduction of (gross) GHG *emissions* (e.g., through fuel switching in the energy sector) and the direct reduction of their *concentrations* (through sequestration or enhancing the sink capacity of biological and other systems).

> **Adaptation:** *Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation. [. . .]*

Adaptation to climate change, as defined by the IPCC, comprises a broad range of actions. Alternative definitions have sometimes restricted the use of this term to adjustments in social systems, to deliberate changes, to major structural changes in a system, or to a subset of climatic stimuli (Smit et al., 2000).

Figure 4 distinguishes four different ways how *adaptation* can influence other elements of the conceptual framework. We illustrate each of these links with an example referring to climate impacts on human health. Vaccination against climate-sensitive vector-borne diseases and early-warning systems for heatwaves are examples of *adaptation* measures that reduce the *sensitivity* and *exposure* of people to climate-related health hazards, respectively. The treatment of people who have already fallen ill can alleviate the *impacts* of climate change without affecting their *exposure* or (initial) *sensitivity* to the stressor. Finally, improving the nutritional conditions of children to enhance their immune status is an example of how *adaptation* can reduce negative *non-climatic factors* which, in turn, reduces the *sensitivity* of this population group to climate-related health hazards.

First-generation vulnerability assessments raise awareness of the (pre-adaptation) vulnerability of valued systems to climate change. They may also assess the relative importance of various climatic and non-climatic factors. In so doing they help to prioritize further research and determine the need for mitigation and adaptation measures to reduce adverse effects of climate change. Depending on the level of adaptation assumed, assessment results may fall anywhere in the range spanned by the 'dumb farmer' and the 'clairvoyant farmer' trajectories in Figure 1. However, as long as the feasibility of implementing adaptations is not assessed, an assessment cannot provide a full picture of the vulnerability of the system under consideration. For a more detailed discussion of adaptation assumptions and examples of studies that could be regarded as first-generation vulnerability assessments in our classification, see Smithers and Smit (1997) and Smit and Pilifosova (2001). Most initial national communications to the UNFCCC produced by developing countries are also first-generation vulnerability assessments (Lim, 2001).

3.5. SECOND-GENERATION VULNERABILITY ASSESSMENT

Second-generation vulnerability assessments are conducted to estimate realistically the vulnerability of certain sectors or regions to climate change, in concert with other stress factors and considering the potential of feasible adaptations to reduce adverse impacts. They acknowledge that it is not the mere availability of adaptation options but the capacity of people to actually implement these options that determines their vulnerability to climate change. The main difference, compared to first-generation vulnerability assessments, is thus the more thorough assessment of society's ability to effectively respond to anticipated risks through various kinds of adaptations. In so doing they help to prioritize the allocation of resources for adaptation measures. If limits to adaptation are identified for valued systems, this provides important information for the determination of critical levels of climate change. The results correspond most closely to the 'realistic farmer' trajectory in Figure 1.

The conceptual framework for a second-generation vulnerability assessment is shown in Figure 5. Two elements have been added in comparison to Figure 4.

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

The **adaptive capacity** of a system or society describes its ability to modify its characteristics or behaviour so as to cope better with changes in external conditions.

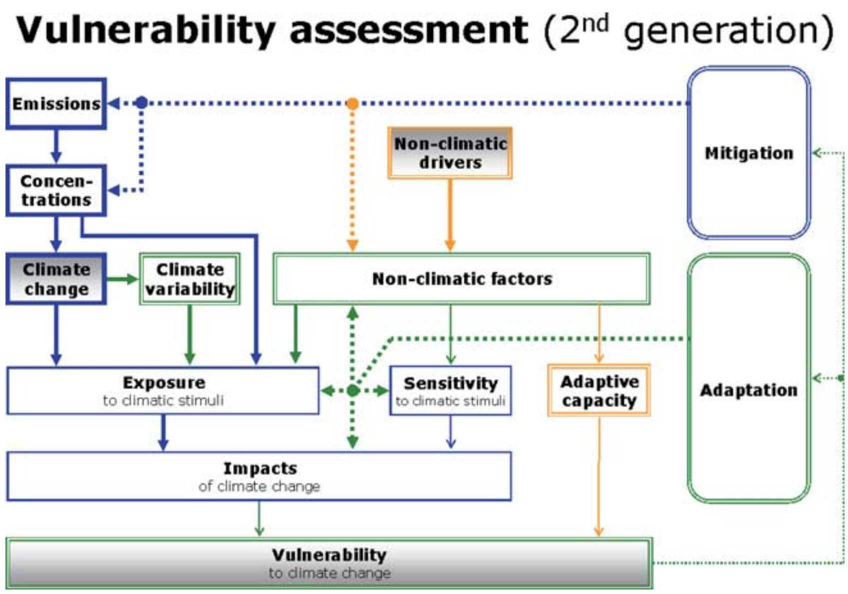

Figure 5. Conceptual framework for a second-generation vulnerability assessment.

Under *ceteris paribus* conditions, *adaptive capacity* and *vulnerability* are negatively correlated. It should be noted that the IPCC definitions for 'adaptive capacity' (as well as of 'adaptation' and 'vulnerability') refer to social and natural systems alike.

Brooks (2003) classifies factors that determine adaptive capacity into hazard-specific and generic factors, and into endogenous and exogenous factors. Generic determinants of *adaptive capacity* in social systems comprise such *non-climatic factors* as economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit and Pilifosova, 2001; Yohe and Tol, 2002). Endogenous factors refer to the characteristics and behaviour of the considered population group whereas exogenous factors include the wider economic and geopolitical context. The cross-scale nature of *adaptive capacity* is reflected in Figure 5 by the double border around the respective box. Since the ability of social systems to cope with current climate variability is an important indicator for their capacity to adapt to future climate change, analyses of vulnerability to current climate variability across systems or regions can provide important lessons for adaptation science (Bohle et al., 1994).

An important element in second-generation vulnerability assessments is the explicit consideration of relevant **non-climatic drivers** (e.g., demographic, economic, sociopolitical, technological, and biophysical drivers). These drivers affect relevant *non-climatic factors* (e.g., the degree of economic diversification, the level of education, and the strength of social networks) that, in turn, determine the *sensitivity* of a system or community to climate change. In the context of climate change vulnerability assessments, large-scale processes associated with global change, such as economic globalization and urbanization, are particularly important. A recent effort to assess the combined effects of climate change and economic globalization is the 'double exposure' project (O'Brien and Leichenko, 2000; O'Brien et al., 2004b). Because our framework focuses on vulnerability to climate change, we do not further distinguish between different types of *non-climatic drivers*.

For some countries, *mitigation* actions (both within the considered region and abroad) can affect relevant *non-climatic factors*. Examples include "*the adverse effects [...] of the implementation of response measures [...] [on countries] whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and on the welfare of regions where energy production is a major income source*" (UNFCCC, Article 4.8).

Second-generation vulnerability assessments are not yet commonplace, in absence of a clear methodology. More than first-generation assessments they require the involvement of social scientists in a multidisciplinary research group. In addition, second-generation assessments require a stronger involvement of stakeholders and, focusing more on adaptive capacity, rely more heavily on qualitative data. The *Assessments of Impacts of and Adaptation to Climate Change in Multiple Regions and Sectors* (AIACC) project (which is implemented by the United Nations

Environment Programme and supports the development of scientific and technical capacity amongst developing country scientists to address gaps in knowledge about climate change impacts, vulnerability, and adaptation) includes a number of subprojects that could be considered second-generation vulnerability assessments. Other studies that are most appropriately classified as second-generation vulnerability assessments are the *National Assessment of the Potential Consequences of Climate Variability and Change for the United States* (National Assessment Synthesis Team, 2001; Scheraga and Furlow, 2001), as well as Adger (1999) and Cohen et al. (2000).

3.6. ADAPTATION POLICY ASSESSMENT

The three assessment stages presented so far were primarily concerned with providing increasingly realistic estimates of the risks to society due to anthropogenic climate change. This impacts-driven type of research provides important information to scientists and policy-makers, in particular for the prioritization of additional research and for the design of mitigation policy. Burton et al. (2002) provide five explanations why it usually has *not* provided adequate information for the development of adaptation policy:

- Insufficient consideration of more pressing immediate and short-term policy issues, in particular in developing countries.
- Insufficient knowledge of future climate conditions on the scale relevant for adaptation decisions.
- Insufficient consideration of diverse adaptation options in most climate impact models.
- Insufficient consideration of the factors determining the adaptation process itself, including adaptive capacity.
- Insufficient consideration of key actors and of the policy context for adaptation.

The fourth stage in our conceptual framework refers to assessments that directly address the information needs of adaptation decision-makers. We use the term ‘adaptation policy assessment’ to emphasize that the main purpose is to contribute to policy-making by providing specific recommendations to planners and policy-makers on the enhancement of adaptive capacity and the implementation of adaptation policies. Scheraga and Furlow (2001) emphasize that decision-makers require very specific types of information in order to design and implement effective adaptive responses, and that uncertainties about future climate change and its impacts are a crucial issue in this context. Employing the language of Figure 1, adaptation policy assessments aim to prevent ‘avoidable impacts’ by turning ‘typical farmers’ into ‘smart’ ones. More than previous assessment stages, this objective requires intense collaboration of assessors with different scientific backgrounds, such as climatology, mathematical modelling, economy, human geography, and policy analysis. The most suitable methods and tools for adaptation assessment vary widely across impact domains, regions, assessment levels, and target decision-makers.

Adaptation policy assessments correspond broadly to 'Type 2' adaptation research, which is characterized in Burton et al. (2002) by its focus on social determinants of vulnerability, its start from the current vulnerability of societies to climate variability, and its emphasis to design adaptation policy from existing policies rather than from the scratch. Adaptation policy assessments need to examine in detail the available response options, including considerations as to the feasibility of their implementation and to their compatibility with other policy goals such as sustainable development, economic diversification, and biodiversity conservation. A continuous dialogue between assessors and relevant stakeholders is indispensable to this end.

Figure 6 shows the conceptual framework for an adaptation policy assessment. (For the sake of completeness, mitigation actions are also included.) Not all of the above-mentioned differences between the assessments described before and an adaptation policy assessment can be reflected in our conceptual framework. The diagram focusses on the different steps of adaptation, on the relation between adaptation and adaptive capacity, and on the changes in the main 'inputs' and 'outputs' of the assessment.

Two types of *adaptation* activities are distinguished in Figure 6. **Facilitation** refers to activities that enhance *adaptive capacity*, such as scientific research,

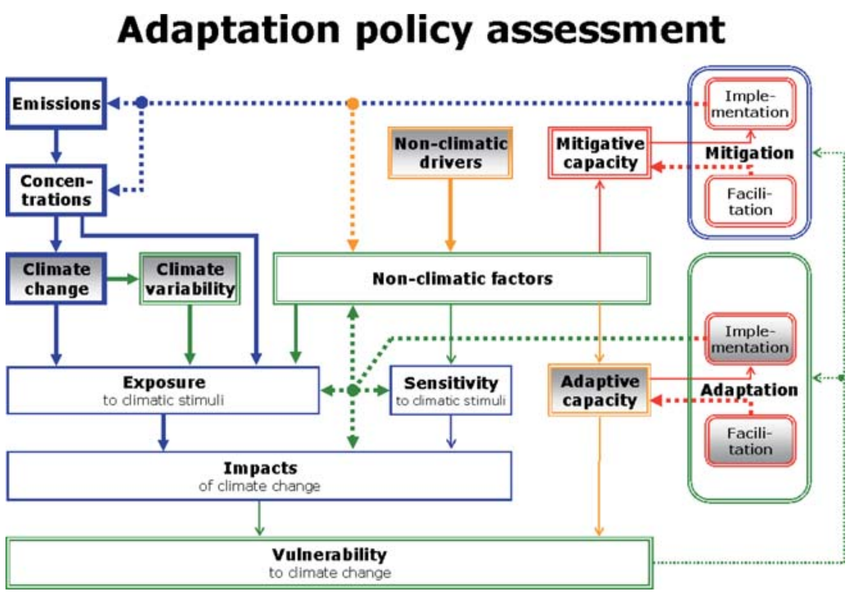

Figure 6. Conceptual framework for an adaptation policy assessment.

data collection, awareness raising, capacity building, and the establishment of institutions, information networks, and legal frameworks for action. **Implementation** refers to activities that actually avoid adverse climate *impacts* on a system by reducing its *exposure* or *sensitivity* to climatic hazards, or by moderating relevant *non-climatic factors* (see Section 3.4 for examples). The relationship between *adaptive capacity* and *adaptation* in the conceptual framework is two-fold. *Adaptive capacity* determines the feasibility of the *implementation* of adaptation, and it is itself influenced by measures that would be considered as *facilitation* of adaptation.

The *mitigation* part of the conceptual framework has the same structure as the *adaptation* part. The **mitigative capacity** of a region, sector, or other social unit may be enhanced by **facilitation** measures, such as the establishment of a carbon trading scheme. An example for an **implementation** measure is the replacement of an old power plant by a less carbon-intensive one, which may have become economically viable due to the possibility for trading carbon permits. The concept of *mitigative capacity* has been introduced into the literature only recently (Yohe, 2001). *Mitigative capacity* is affected by various *non-climatic factors*. For instance, the effectiveness of a carbon trading scheme in reducing greenhouse gas *emissions* is partly determined by the presence and effectiveness of appropriate institutional arrangements in the respective region.

Figure 6 shows a major change in the main drivers of the assessment and in its primary results, as reflected by the shading of selected boxes. *Climate change* is just one of the drivers of an adaptation policy assessment, along with *climate variability* and other *non-climatic drivers*. Another important input is current *adaptive capacity*, which determines both the scope and the need for future *adaptation*. The main result of an adaptation policy assessment are recommendations for specific *adaptation* strategies, including both *facilitation* and *implementation* measures, rather than estimates of future *impacts* or *vulnerability* to climate change.

To date, there is limited guidance for full-blown adaptation policy assessments. An important initiative to advance the state of the art is the development of an *Adaptation Policy Framework* for Stage II adaptation under decision 11/CP.1 of the UNFCCC (Lim, 2001; UNDP, 2003). The development of this framework is guided by the United Nations Development Programme (UNDP). Füssel and Klein (2004) have reviewed a wide range of conceptual frameworks for adaptation as to their suitability for adaptation policy assessments for human health. Some of their observations and recommendations are also valid for other impact domains. One example of an adaptation policy assessment is the project *Climate Change and Adaptation Strategies for Human Health in Europe* (cCASHh), which has assessed the status of adaptation possibilities of communities to climate-related impacts on human health in Europe with the aim of enhancing their adaptive capacity (Menne and Ebi, 2005).

4. Summary and Conclusions

Climate change vulnerability assessments are performed for different purposes: to increase the scientific understanding of climate-sensitive systems under changing climate conditions, to inform the specification of targets for the mitigation of climate change, to prioritize political and research efforts to particularly vulnerable sectors and regions, and to develop adaptation strategies that reduce climate-sensitive risks independent of their attribution. Each of these purposes has specific information needs and thus requires a targeted approach to provide this information.

The evolution of climate change vulnerability assessments shows a trend from assessments that consider the multiple effects of climate change on a particular system to assessments that recommend policy options for minimizing the risks associated with multiple stresses. In this paper, we describe this evolution by distinguishing four prototypical assessment stages. *Impact assessments* superimpose future climate scenarios on an otherwise constant world to estimate the potential impacts of anthropogenic climate change on a climate-sensitive system. *First-generation vulnerability assessments* account for important non-climatic factors and acknowledge the potential for adaptation measures to reduce potential climate impacts. *Second-generation vulnerability assessments* pay particular attention to the ability of a system or population to adapt to climate change. Even though they consider climate change and the potential response options in a wider context, their main purpose is still a descriptive one. *Adaptation policy assessments* aim to contribute to policy-making by recommending specific adaptation measures, thus representing a fundamental shift in the assessment purpose. They are characterized by the intensive involvement of stakeholders, by a strong emphasis on the vulnerability of a population to current climate variability, by the formulation and evaluation of response strategies that are robust against uncertain future developments, and by the integration of adaptation measures with existing policies.

The evolution of the conceptual framework underlying these assessment stages is illustrated by a series of diagrams. Each diagram serves as a consistent visual glossary of the main concepts underlying the IPCC approach to vulnerability for a particular assessment stage, including concepts that are used differently by other research communities (e.g., vulnerability). Different types of analytical relationships between key concepts are distinguished in the conceptual framework to reflect the distinct perspectives of natural and social sciences on the issue. The series of diagrams reflects the increasing complexity of climate change vulnerability assessments over time in response to changing stakeholder needs. The hierarchical presentation of the diagrams shows how each assessment stage depends to some degree on the results from earlier assessment stages.

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