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Assessing adaptation to the health risks of climate change: What guidance can existing frameworks provide?

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Abstract

Climate change adaptation assessments aim at assisting policy-makers in reducing the health risks associated with climate change and variability. This paper identifies key characteristics of the climate-health relationship and of the adaptation decision problem that require consideration in climate change adaptation assessments. It then analyzes whether these characteristics are appropriately considered in existing guidelines for climate impact and adaptation assessment and in pertinent conceptual models from environmental epidemiology. The review finds three assessment guidelines based on a generalized risk management framework to be most useful for guiding adaptation assessments of human health. Since none of them adequately addresses all key challenges of the adaptation decision problem, actual adaptation assessments need to combine elements from different guidelines. Established conceptual models from environmental epidemiology are found to be of limited relevance for assessing and planning adaption to climate change since the prevailing toxicological model of environmental health is not applicable to many climate-sensitive health risks.

Keywords: Adaptation assessment, climate change, conceptual framework, environmental health, public health, vulnerability assessment

1 Introduction

Anthropogenic climate change is an important risk factor for human health [McMichael and Githeko, 2001]. The most recent Global Burden of Disease assessment estimates that 166,000 deaths and 5.5 million disability-adjusted life years (DALYs) in 2000 can be attributed to global climate change [McMichael et al., 2004]. Current health problems may become more (or less) urgent due to future climate change, and new health risks may be introduced to currently unaffected regions.

Most adverse health impacts of climate change can in principle be prevented by appropriate adaptations. The term ‘adaptation to climate change’ is used here to refer to any actions by individuals, social groups, or institutions that are undertaken to avoid, prepare for or respond to the detrimental impacts of observed or anticipated climate change [McCarthy et al., 2001, Glossary]. It should be noted that the term ‘adaptation’ is used differently by some other professional communities. The focus of this paper is on ‘planned adaptation’, which involves conscious planning by the adaptation actor [Smit et al., 1999]. In a nutshell, planned adaptation uses information about current and future climate change to act now on reducing adverse climate impacts whenever the benefits of early action are perceived to exceed the associated costs.

Planned adaptation to the health risks of climate change comprises a wide range of preventive public health measures, ranging from general improvements of the public health system to the development of specific interventions to deal with new risks. While many measures considered in adapting to climate change are not new, adaptation to climate change may require action by individuals or institutions within and outside the public health sector who have not considered climate an important factor for their decisions in the past.

Planning and implementing adaptations to the health impacts of climate change touches upon issues that have traditionally been discussed in the distinct communities concerned with climate and climate change, risk management, public health, and environmental health. Each of these communities has developed conceptual models and assessment approaches to provide the information needed to guide actions within their specific area of responsibility. However, adaptation to anthropogenic climate change contains many unfamiliar elements that limit the applicability of established methods and tools. For instance, scholars with an environmental health background are confronted with the large spatial scale of the climate problem, its long time horizon, the complex spatiotemporal pattern of the hazard, and the large uncertainty of future hazard levels [Woodward and Scheraga, 2003, Kovats et al., 2003a]. An integration of the various assessment approaches is often hampered by differences in terminology, conceptual models, and explanatory concepts.

Efforts to integrate public health with adaptation to climate change and variability have increased recently. Most importantly, Ebi et al. [2005a] presents a number of insightful essays on the links between these two domains: Ebi et al. [2005b] discuss adaptation from a public health perspective; Yohe and Ebi [2005] compare perspectives and key concepts applied by the two communities; Lindner [2005] discusses similarities between the two communities; and Burton et al. [2005b] and Ebi et al. [2006b] present lessons learnt from public health for adaptation policy. Some chapters in McMichael et al. [2003], in particular Grambsch and Menne [2003], also address this link. The present paper aims to complement this literature by evaluating existing assessment guidelines and conceptual models in terms of their relevance for informing planned adaptation to the health risks of climate change and variability. The focus of the discussion is on the scientific aspects of adaptation planning rather than on strategies for overcoming specific political obstacles to their implementation.

It is sometimes argued that priority should be given to the implementation of proven policies to reduce existing health risks rather than to additional analysis of potentially minor hazards, such as climate change. This call for action is consistent with the conclusions from many analyses that insufficient funding for public health is a key obstacle to improved human wellbeing and economic development in many world regions. It is, however, increasingly recognized that many interventions targeted at current climate-sensitive health risks would also reduce vulnerability to future climate change (and vice versa). Science-based assessment that estimate future health risks in the context of the current situation may identify such 'win-win options', which would improve public health now and in the future.

Most national and regional climate change impact and adaptation assessments conducted so far as well as the National Communications supplied to the United Nations Frameworks Convention on Climate Change (UNFCCC) before 2003 have treated health risks only cursorily, or not at all [Kovats et al., 2003a]. More recently, UNFCCC [2005] report that 50 developing countries have included potential health impacts in their National Communications, generally based on qualitative assessments, and some have also suggested generic adaptation measures. Existing climate impact assessments for human health have addressed heat stress, weather disasters (coastal and river flooding, wind storms, and cyclones), air pollution, various vector-borne, food-borne and water-borne diseases, and malnutrition, depending on the specific regional conditions. The consideration of adaptation generally does not exceed lists of potential adaptation options, with the notable exception of a recent European research project [cCASHh, see Menne and Ebi, 2006]. For a more detailed discussion of past climate impact and adaptation assessments for human health, including the methods used, the reader is referred to Kovats et al. [2003a] and Füssel and Ebi [2007]. Unfortunately, *"information on the process aspects of these assessments is not widely available"* [Kovats et al., 2003a, p. 187].

Given the scarcity of climate impact and adaptation assessments for human health at the national and regional level, it is not surprising that few comprehensive assessments have been conducted at the local level. Some communities have analyzed the health risks from heat-waves, flooding, and air pollution, and have considered potential adaptation measures [*e.g.*, London Climate Change Partnership, 2002]. Several guidelines and tools for adapting to climate change at the community level are currently being developed. The Vulnerability and Response Assessment for Climate Change framework (VARA; `http://public.ornl.gov/vara/`) developed by the U.S. Agency for International Development offers cities assistance with assessing possible impacts of climate variability and change and considering responses to reduce their vulnerabilities to such impacts. A consortium led by the World Conservation Union is developing the Community-based Risk Screening Tool – Adaptation and Livelihoods (CRISTAL; `http://www.iucn.org/climate`), which aims to help communities in developing countries to understand the impacts of climate change on livelihoods and to improve their capacity to cope with them. The Canadian Climate Impacts and Adaptation Research Network (C-CIARN) has published adaptation guidelines that complement the national climate impacts and adaptation guidelines with a specific focus on Canadian municipalities [Mehdi et al., 2006].

This paper focusses on guidelines for national and regional adaptation policy assessments that aim at providing policy-relevant information to assist health managers and other relevant actors in reducing the health risks associated with climate change and variability. It is structured as follows. Sect. 2 provides an introduction to climate impact and adaptation assessments and identifies key features of the adaptation decision problem that need to be considered in adaptation assessments for human health. Sect. 3 evaluates existing assessment guidelines in terms of their relevance for assessing adaptation to the health risks of climate change. This evaluation is based on the criteria developed in Sect. 2 and on the experience of past vulnerability and adaptation assessments. Sect. 4 assesses the applicability of conceptual frameworks from environmental epidemiology and comparative risk assessment for climate change adaptation assessment. Sect. 5 summarizes the key findings.

2 Planned adaptation to climate change

2.1 Types of climate change assessments

Assessments of the risks from climate change and of potential adaptations to reduce these risks can serve different scientific and policy objectives. Füssel and Klein [2006] have suggested the following classification of climate change assessments based on the decision context in which their results are primarily applied:

Climate impact assessments aim at "identifying and evaluating the detrimental and beneficial consequences of climate change on natural and human systems" [McCarthy et al., 2001]. They bring attention to the anticipated *incremental* effects of anthropogenic climate change and assess the potential for constraining them by reducing the magnitude and rate of climate change. Climate impact assessments are most useful for the specification of long-term targets for climate change mitigation and for the identification of priority research needs.

Climate vulnerability assessments (distinguished further into first-generation and second-generation vulnerability assessments) integrate the results of climate impact assessments in a broader social context. This is achieved by assessing climate change together with other stressors to a system; by evaluating impacts in terms of their importance for society; and by considering the potential of feasible adaptations to reduce adverse impacts. The main goal of a first-generation vulnerability assessment is to assess the importance of global climate change for a particular system, sector, or community. The main goal of a second-generation vulnerability assessment is to identify regions or communities that are particularly vulnerable to climate change as a basis for prioritizing the allocation of resources to plan and implement adaptation measures. A key aspect of second-generation assessments is an analysis of 'adaptive capacity', which denotes the ability of a social system to adjust to climate change, as determined by social, institutional, economic, political, and cultural factors [Brooks et al., 2005].

Adaptation policy assessments aim at designing and recommending adaptation strategies that reduce the vulnerability of a specific region or sector to climatic stressors now and in the future. Since these assessments integrate climate change with other policy concerns, they require close interaction with the target stakeholders throughout the assessment.

Burton et al. [2005a] distinguish four approaches to climate change adaptation assessment that focus on different aspects of the adaptation context [for a different classification, see Dessai et al., 2005]:

Hazards-based approach: Analyze possible outcomes from a specific climate hazard.

Vulnerability-based approach: Determine likelihood that current or desired vulnerability of a social system may be affected by future climate hazards.

Adaptive-capacity approach: Analyze the barriers to adaptation and propose how they can be overcome.

Policy-based approach: Investigate the efficacy of an existing or proposed policy in light of a changing exposure or sensitivity.

The relative suitability of these approaches in a specific assessment context depends on a multitude of factors, including the current level of climate-related health risks, the time horizon of relevant adaptation options, and the availability and reliability of model-based climate change scenarios and relevant epidemiological data. These factors vary widely across health effects and study regions.

Kovats et al. [2003a] distinguish four increasingly complex stages of adaptation assessment for human health:

1. List of adaptation options without evaluation
2. Estimation of the health benefit or effectiveness of specific adaptation strategies
3. Evaluation of specific adaptation strategies (*e.g.*, using cost-effectiveness analysis)
4. Policy analysis that addresses the feasibility of specific adaptation strategies

2.2 Prerequisites for planned adaptation

Last [1998] has identified five prerequisites for the control of any public health problem:

1. Awareness that the problem exists
2. Understanding what causes the problem
3. Capability to deal with the problem
4. A sense of values that the problem matters
5. Political will to control the problem

These prerequisites are also relevant for planned adaptation to climate change. Füssel and Klein [2004] have modified this list to reflect the fact that adaptation to global climate change is largely concerned with potential future risks and that not all adaptations will be implemented by public agencies. They also distinguish between two aspects of the "capability to deal with the problem": resource availability and cultural acceptability. As a result, they suggest the following prerequisites for effective planned adaptation (assuming that a significant climatic risk exists either now or in the future):

1. Awareness of the problem

2. Availability of effective adaptation measures
3. Information about these measures
4. Availability of resources to implement these measures
5. Cultural acceptability of these measures
6. Incentives for implementing these measures

All prerequisites have to be fulfilled to a certain degree for adaptation to be effective. Vulnerability and adaptation assessments can potentially address each of them (to some degree) by identifying significant problems and raising awareness of them (1), by identifying effective adaptation measures (3), by identifying co-benefits of adaptation or facilitating the provision of additional resources (4), by educating people in order to raise the acceptability of certain measures (5), by advising on the creation of incentives for actually implementing these measures (6), and by triggering research that may develop new adaptation options (2).

The main obstacles to successful adaptation vary from one decision context to another. Hence, scientific analysis and political efforts should be targeted at those elements that are most in need of improvement. For instance, if there is little awareness among policy-makers and other stakeholders of the health risks associated with climate variability and change, the assessment should focus on highlighting these risks as well as the risk-reducing potential of adaptive measures. If stakeholders are aware of the risks but have little information what to do about them, the assessment should suggest feasible and effective measures, considering the experiences of dealing with similar risks in already affected regions. If stakeholders are aware of the risks and knowledgeable about effective response measures, the assessment is more likely to focus on the expected costs and benefits of the specific options available, and on overcoming potential barriers to their implementation. Adaptation policy assessments are least relevant if all prerequisites to adaptation are already fulfilled (denoted as 'autonomous adaptation') or when unsurmountable obstacles exist to fulfilling some prerequisite (denoted as fundamental or practical 'limits of adaptation').

2.3 Ten characteristics of the adaptation decision problem

The following list presents ten key characteristics of the decision problem encountered in planning adaptation for the health risks from climate change, and it discusses their implications for adaptation policy assessment [see also Woodward and Scheraga, 2003, Scheraga et al., 2003].

1. **Climate change is a complex and uncertain hazard.**

   Planned adaptation to climate change is largely motivated by climatic changes that are anticipated to occur in the future. Climate as well as anthropogenic climate change are complex phenomena involving many variables that vary on different spatial and temporal scales. The ability to forecast complex climatic conditions is limited by decision uncertainty about future greenhouse gas emissions and by scientific uncertainty about their effects on the global and regional climate. While changes in average climate parameters such as seasonal temperature can often be described by (subjective) probability distributions, this approach becomes increasingly difficult for extreme weather events and complex climatic stimuli. Consequently, the applicability of established methods from quantitative health risk assessment in climate impact and adaptation assessment is often limited.

2. **Climatic changes affect human health along very diverse causal relationships.**

   The "health impacts" of climate change integrate a wide range of climatic effects on society. Their integrative aspect is similar to the "economic impacts" of climate change, which comprise effects on agriculture, settlements, industries, and other impact domains. Climate-sensitive health risks include those occurring as a direct consequence of exposure to climatic stimuli (*e.g.*, heat stroke, drowning during flood), those mediated via climate-sensitive ecological systems (*e.g.*, water-borne and vector-borne diseases), and those resulting from the wider social implications of climate change (*e.g.*, malnutrition). A comprehensive climate change assessment for human health needs to review the main effects of climate change on other sectors since this information may be crucial for assessing future health risks.

3. **The causal relationship between climate and health can be extremely complex, and relevant epidemiological data is often scarce.**

   The effect of climatic hazards on the health of individuals and populations is determined by a variety of non-climatic factors, such as wealth, nutritional status, accessibility of health services, acclimatization, and behavioural factors. As a result, the epidemiological relationship between climatic factors and specific health outcomes is highly population-specific, limiting the informative value of epidemiological data from spatial analogues. Temporal analogues are often not available because anthropogenic climate change will expose populations to climatic conditions that they have never experienced before. Finally, hypotheses of the effects of climate on health cannot be tested in experimental studies because climate cannot be randomly assigned to populations. Adaptation policy assessments need to consider the complexity of the climate-health relationship as well as the availability of pertinent epidemiological data in the study region when choosing between quantitative, semi-quantitative, and qualitative assessment approaches. The less epidemiological data is available, the more important it is generally to actively seek for and include the experiential knowledge of regional stakeholders.

4. **Uncertainty in future risk projections is generally large but it varies across regions and health outcomes.**

   The uncertainty in projections of climate change impacts is generally larger for human health than for other climate-sensitive sectors where adaptation has been considered initially (*e.g.*, agriculture, coastal zones). However, the level of uncertainty varies widely across health outcomes and regions depending on the complexity of the climate-health relationship and the availability of epidemiological data. Adaptation policy assessments need to address key uncertainties and evaluate their implications for policy decisions. Even in the presence of very large uncertainty about future risk levels, adaptation assessments may be able to recommend cost-effective measures (*e.g.*, no/low-regret or win-win options, prevention of maladaptation).

5. **Adaptation involves a diverse group of actors.**

   The reduction of climate-sensitive health risks may involve a diverse group of public and private actors from different sectors. Some climate-sensitive health impairments can be addressed largely within the public health sector but many of them require concerted actions with other sectors (*e.g.*, meteorological services, urban and spatial planning, development and housing, agriculture). Adaptation policy assessments should identify key adaptation actors from all relevant sectors early in the process and consider their specific information needs, including appropriate spatial and temporal scales. Adaptation strategies need to consider intersectoral and cross-sectoral action in addition to sectoral activities.

6. **Climate change is a long-term hazard but the planning horizon of adaptation varies across regions, health outcomes, and measures.**

   Anthropogenic climate change unfolds over a time scale of several centuries but adaptations to reduce its adverse health effects have very different lead times. Some measures can be implemented quickly if need arises (*e.g.*, stocking up of medical supplies), others require a few years' time (*e.g.*, establishing a heat-wave warning system), and still others take decades before they are fully effective (*e.g.*, changes in town planning to reduce the urban heat island). The planning horizon of potential adaptations has important implications for vulnerability and adaptation assessment as it largely determines the policy horizon of the risk assessment.

7. **Human health is already strongly managed.**

   Human health is already strongly managed as most countries have a public health system in place to reduce major risks to population health. Therefore, the most efficient way to reduce climate-sensitive health risks is generally by building upon existing policies and institutions, in particular if the health risk concerned is already prevalent in a region.

8. **Most adaptations to future climate change also reduce vulnerability to current climate variability.**

   The effectiveness of a public health intervention to reduce the health risks of a particular climatic event is independent of its attribution to natural factors or anthropogenic influence. Therefore, adaptations aimed at reducing climate-sensitive health risks that are already prevalent today will also reduce current health risks, and their effectiveness should be evaluated under current as well as changed climate conditions.

9. **Social conditions for adaptation vary widely across regions.**

   Different regions vary widely with respect to the level of socioeconomic development, the availability and accessibility of public health infrastructure and services, the current health status of the population, the availability of data and expertise to produce and/or use sophisticated climate scenarios, the infrastructure and financial resources for the implementation of adaptation measures, the time horizon of policy decisions, and cultural preferences. Consideration of these factors is crucial in adaptation policy assessments as they determine the importance of current health risks *vs.* future health risks, the suitability of different assessment approaches, and the feasibility of specific adaptation options. For instance, those countries with very inadequate health delivery now (*i.e.*, many developing countries) should focus on understanding and managing current climate-sensitive health risks in a way that also reduces vulnerability to climate change. Countries where current health risks are adequately controlled, in contrast, should focus on assessing whether current control measures are still adequate in a changing climate.

10. **Adaptation and adaptation assessment is subject to resource constraints.**

    Adaptation to the health risks of climate change competes with other public health policies for limited resources. Such resource constraints are particularly severe in countries that are currently burdened with high disease levels. Merely listing adaptation options provides little guidance for decision-makers challenged with allocating these resources to their 'best' use. Adaptation policy assessments should therefore attempt to evaluate different options in terms of their effectiveness and urgency, at least qualitatively. Since resources for adaptation assessment are limited as well, assessments should focus on those health risks, regions, and population groups where additional information is most important for supporting good policy. In general, this goal can be best achieved by a multi-tiered assessment where the full range of potential health risks and adaptation options is screened in a first tier, and the most important risks are assessed more thoroughly in a second (and potentially a third) tier.

The discussion above shows that adaptation to the health risks from climate change involves several unfamiliar challenges for adaptation planners. Key implications for adaptation policy assessment are to assess the relative importance of climate change compared to other risk factors in a given decision context; to integrate adaptation to climate change and variability with existing management policies (denoted as 'adaptation mainstreaming'); to deal explicitly with uncertainties; and to reflect which additional information is most relevant from a policy perspective. Guidelines for human health adaptation assessment need to be flexible enough to accommodate the substantial diversity of regional conditions, health outcomes, and adaptation actors.

3 Guidelines for adaptation policy assessment

Several organizations have developed guidelines for climate change impact and adaptation assessment. These guidelines describe the main steps involved in assessing vulnerability to climate change and developing effective adaptation strategies, and they provide guidance on how to implement these steps. Some guidelines are generic (*i.e.*, intended to be applicable to any climate-sensitive impact domain anywhere in the world) whereas others are targeted at specific systems, sectors, or world regions. Earlier guidelines tend to focus on impact assessment whereas later guidelines put more emphasis on adaptation planning. Adaptation guidelines have also been developed by some organizations responsible for managing or funding climate-sensitive resources [*e.g.*, Global Environment Facility Program, 2006].

This section reviews the main guidelines for climate impact and adaptation assessment in terms of their ability to provide guidance for national and regional adaptation policy assessments for human health. It does *not* judge the general "quality" of these guidelines, which have been developed for different audiences and with different objectives. Table 1 summarizes the results of this review by indicating the degree to which each guideline meets several criteria derived from the discussion in the previous section. Several caveats should be mentioned in this context. First, the assessment may have been influenced by the practical experience with climate impact and adaptation assessments described in the literature. The usefulness of any assessment, however, depends not only on the suitability of the underlying guideline but also on other factors, such as resource availability and the experience of the analysts. Second, the applicability of a guideline may change with scientific progress, *e.g.*, with an improved ability to project climate change on the regional level. Finally, any such evaluation unavoidably contains subjective elements. The remainder of this section discusses each of the six guidelines mentioned in Table 1 in more detail.

3.1 IPCC Technical Guidelines

The IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations [Carter et al., 1994] constitute the first comprehensive approach

	IPCC 1994 3.1	USCSP 1996 3.2	UNEP 1998 3.3	UKCIP 2003 3.4	UNDP 2005 3.5	WHO 2003 3.6
Clear procedural structure	+	+	o	+	+	o
Flexible assessment procedure	o	o	o	+	+	o
Prioritization of assessment efforts	o	o	o	+	o	o
Identification of key information needs	−	−	−	+	o	o
Inclusion of key stakeholders	−	o	o	o	+	+
Choice of relevant spatial and temporal scales	−	o	o	+	+	o
Balanced consideration of current and future risks	−	o	o	o	+	+
Management of uncertainties	o	o	o	+	+	o
Policy guidance in the absence of quantitative risk estimates	−	−	o	+	+	o
Prioritization of adaptation actions	−	o	o	+	+	-
Mainstreaming of climate adaptation	−	o	o	+	+	+
Cross-sectoral integration	o	o	+	−	+	+
Disease-specific methods and tools	−	o	+	−	−	+
Assessment of key obstacles to adaptation	−	−	−	−	o	o

Table 1: Suitability of major guidelines for climate impact and adaptation assessment in the context of national and regional adaptation assessments of human health. Top row: responsible institution; second row: publication year; third row: cross-reference to section in this paper. Symbols indicate degree to which a specific criterion is met (+: good; o: partial; −: weak).

for guiding impact and adaptation assessments. They aim at guiding analysts through the various methods that can be used to assess the impacts from, and adaptations to, climatic changes, and at structuring the assessment process. The Technical Guidelines implement the hazards-based (or scenario-based) approach to climate change impact and adaptation assessment. Their development was heavily influenced by the experiences of various modelling groups who combined model-based climate scenarios with biophysical climate impact models to project the impacts of climate change on food production, natural ecosystems, and freshwater hydrology. The Technical Guidelines are intended to be applicable in different sectors and geographical regions, and in countries at different levels of economic development. However, their applicability is crucially dependent on the availability of reliable projections for future changes in relevant climatic and non-climatic risk factors, and of simulation models for projecting the impacts of these changes. Most of the examples presented refer to climate impacts on natural ecosystems and agriculture [Carter et al., 1994, Parry and Carter, 1998]. Health impacts are addressed but the focus is cursorily and on scenario-driven modelling.

The hazards-based approach to climate change assessment focusses on estimating long-term impacts of climate change rather than facilitating adaptation. It is better suited to biophysical impacts where quantitative impact models are available than to socioeconomic and health impacts. Impact projections have generally been made at highly aggregated levels, reflecting the spatial scale at which climate scenarios have been typically available. Adaptation needs in the hazards-based approach follow exclusively from the *incremental* effects of anthropogenic climate change. As a result, this approach provides little guidance to countries and regions that lack the data, models, expertise, or resources required to conduct quantitative impact assessments, and it is of limited help if the uncertainty in climate impact projections is very large.

Several reviews have suggested a number of reasons why the hazards-based approach has yielded few results that are immediately useful for the purposes of adaptation policy design [Klein et al., 1999, O'Brien, 2000, McMichael et al., 2001, Burton et al., 2002, Kovats et al., 2003a]:

- strong reliance on model-based climate and climate impact projections, which may not be available in all regions or may not give reliable estimates of future changes in risk levels at the spatial scale relevant for the decision-maker;
- long time frame of climate change projections has little practical relevance for most health-related adaptation measures;
- little consideration of current risks associated with natural climate variability and non-climatic stressors;
- lack of consideration of uncertainties related to costs and benefits of measures and their implications for the design of robust adaptation policies;

- little consideration of non-technical aspects of adaptation, including adaptive capacity and the social determinants of vulnerability;
- little consideration of the wider policy context of adaptation (*e.g.*, sustainable economic development and natural resource management);
- little guidance on involving relevant stakeholders.

The reviews agree in the importance of using assessment methods that can deal with various levels of uncertainty, and of designing adaptation policies that are effective under different plausible climate and socioeconomic scenarios,

3.2 USCSP Handbook

The United States Country Studies Program (USCSP) has developed a handbook (sometimes called the 'International Handbook') for climate vulnerability and adaptation assessment that was intended to be used in tandem with the IPCC Technical Guidelines. Main innovations are the emphasis on involving stakeholders throughout the assessment and the recommendation that impact/vulnerability assessment and adaptation assessment are conducted largely in parallel.

The original USCSP Handbook [USCSP, 1994] focusses on agriculture and forestry, water resources, and coastal zones. The book version of the USCSP Guidelines [Benioff et al., 1996] also includes a chapter on human health vulnerability assessment. Recognizing the limited knowledge about the relationship between climatic factors and human health, a vulnerability-based 'bottom-up' approach is recommended that starts by assessing the sensitivity of current public health issues to anticipated climate change. No specific guidance is given on assessing adaptation options for human health.

Evaluations of the USCSP Handbook for adaptation assessments largely agree with those of the IPCC Technical Guidelines. Smith and Lazo [2001] note that country studies within the USCSP were generally limited to analysis of first-order biophysical effects, and that there were only some limited studies of adaptation. Only two out of 56 countries participating in one of the two phases of the USCSP completed an assessment of human health vulnerability, and only one considered potential adaptation measures [USCSP, 1999, Smith and Lazo, 2001]. Apparent reasons for the minor role of adaptation assessment in USCSP studies are that the training of in-country experts focussed on scenario-based climate impact assessment, and that regional impact projections were often too uncertain to warrant adaptive action now in countries where current climate risks are insufficiently managed.

3.3 UNEP Handbook

The UNEP Handbook on Methods for Impact Assessment and Adaptation Strategies [Feenstra et al., 1998] was designed to assist developing countries and economies in transition in conducting climate impact assessments and identifying adaptation options. The UNEP Handbook consists of two parts. The generic part largely follows the scenario-based approach presented in the IPCC Technical Guidelines. The sectoral part provides specific advice on methods and tools that can be applied in various climate-sensitive impact domains, including human health. The focus of the UNEP Handbook is still on assessing impacts and vulnerability rather than facilitating adaptation.

The UNEP Handbook does not suggest a generic procedural framework for climate impact and/or adaptation assessment but the health chapter [Balbus et al., 1998] tentatively suggests four initial steps for a health impact assessment. The health chapter provides useful recommendations on assessing changes in various climate-sensitive health risks and it discusses specific adaptation strategies to reduce those risks. It emphasizes that health risks should be considered in the context of climate impacts projected for other sectors. A basic consideration of the health chapter is the large uncertainty in projections of future health risks. Consequently, there is a strong focus on linking climate adaptation with the management of current climate-sensitive health risks. Actual assessments following the UNEP Handbook have faced similar problems as those reported above for the IPCC Technical Guidelines [O'Brien, 2000, Kovats et al., 2003a].

3.4 UKCIP Framework for Climate Adaptation

The United Kingdom Climate Impacts Programme (UKCIP) has developed a framework for adaptation decision-making [Willows and Connell, 2003]. The overall objective of this framework is to provide guidance to decision-makers to account for the risk and uncertainty associated with climate variability and change, and to facilitate good adaptation to climate change. The framework aims to be applicable to climate-sensitive decisions by private and public decision-makers in the United Kingdom from all climate-sensitive sectors and at various levels of decision-making.

The UKCIP framework is distinctive in that it casts the assessment process in terms of risk management under uncertainty. However, it also deals with situations where large uncertainties prevent the application of traditional risk assessment techniques. The adaptation process is split into the following key stages:

1. Identify problem and objectives
2. Establish decision-making criteria

3. Assess risk
4. Identify options
5. Appraise options
6. Make decision
7. Implement decision
8. Monitor results

Key characteristics of the UKCIP Framework are that it is *circular*, allowing the performance of decisions taken to be reviewed, and decisions revisited through time; it is *iterative*, allowing the problem, decision-making criteria, risk assessment and options to be refined prior to any decision being implemented; and certain stages within the framework are *tiered*, allowing the decision-maker to undertake screening, evaluation and priority-setting of climate risks and adaptation options before moving on to more detailed risk assessments and options appraisals. The UKCIP report includes several case studies related to coastal management and natural resource management. Treatment of climate impacts on human health is only cursorily.

The UKCIP Framework provides comprehensive and detailed guidance on climate adaptation decision-making, and it addresses most challenges of the adaptation decision problem discussed in Sect. 2.3. In particular, it emphasizes the importance of a careful scoping of the assessment together with affected stakeholders, considering the planning horizon of potential adaptations; it assesses the relative importance of future climate change in a particular decision context, compared to current climate variability and non-climatic factors; it calls for addressing uncertainties in all steps of the assessment; it advocates a multi-tiered assessment so that assessment efforts can be concentrated on those areas where additional information is most important for better decision-making; it provides flexibility in adjusting earlier decisions based on new information; it highlights the importance of no-regret and low-regret options in the presence of large uncertainties; it discusses a wide range of quantitative as well as qualitative tools for evaluating alternative adaptation options; and it provides some guidance for prioritizing adaptations.

The main limitation of the UKCIP framework in the context of this paper is its inability to reflect the diversity of regional adaptation contexts. Since the framework was specifically designed to be applied in the UK, it assumes the availability of sophisticated regional climate scenarios, a considerable level of scientific knowledge, economic resources, and societal awareness, and a rational decision-making culture. Furthermore, the framework also assumes a satisfactory management of current climate-sensitive risks. These assumptions do not necessarily apply in other regions, in particular in many developing countries. Another limitation of the UKCIP framework is that it starts the assessment when a pending decision has already been identified as potentially sensitive to climate change by the decision-maker. Consequently, it does not provide specific guidance on identifying decisions that are potentially sensitive to climate change, on identifying relevant stakeholders, and on raising awareness of the issue of climate change (see Sect. 2.2).

In summary, the UKCIP Framework provides detailed yet flexible guidance for risk-based adaptation policy assessment. It is most suitable in decision contexts where current risks are satisfactorily managed, and where considerable data and knowledge are available for assessing future risks. Since the framework assumes that a decision-maker has already identified a pending climate-sensitive decision, a national or regional adaptation policy assessment for human health would have to include initial steps in which climate-sensitive health issues are screened, potentially affected decision-makers are identified, and awareness of the relevance of climate change for their field of responsibility is raised.

3.5 UNDP-GEF Adaptation Policy Framework

The Adaptation Policy Framework (APF) project was initiated by the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF) to provide guidance to developing countries for conducting adaptation policy assessments in any sector. It was developed in response to the experience gained from applying the hazards-based approach to climate impact and adaptation assessment that treatment of adaptation has rarely gone beyond the listing of potential adaptation options. The APF consists of a User's Guidebook and nine Technical Papers (TPs) published in a single volume [Burton et al., 2005a]. The technical papers refer to different steps in the assessment approach; the amount of sector-specific information is limited.

Key innovations of the APF are that it treats policy as the overarching purpose (and vulnerability and impacts as subordinate to it); it starts by assessing the effectiveness of coping with recent climate experiences rather than by developing model-based climate scenarios; it links adaptation to climate change with adaptation to current climate variability and extremes; it assesses climate adaptation in the context of sustainable development; it combines national policymaking with a "bottom-up" risk management approach at the local scale; and it emphasizes the importance of the stakeholder process through the adaptation assessment.

The overall assessment approach of the APF consists of the following consecutive components:

1. Scoping and designing an adaptation project
2. Assessing current vulnerability

3. Assessing future climate risks

4. Formulating an adaptation strategy

5. Continuing the adaptation process

Each component is further divided into several specific tasks. Two cross-cutting processes of engaging stakeholders and assessing and enhancing adaptive capacity are conducted in parallel to these five steps.

The APF is currently being tested within the context of the regional GEF project *Capacity Building for Stage II Adaptation in Central America, Cuba and Mexico*. Burton et al. [2005a, Secton III] briefly present a case study on human health but this study does not include all APF components.

The APF addresses most of the challenges of the adaptation decision problem discussed in Sect. 2.3. First of all, it advocates a flexible assessment approach that is tailored to the specific information needs of the adaptation actor(s) concerned. The APF regards the various approaches to climate impact and adaptation assessment as complementary, and it provides some guidance for choosing between the natural hazards-based and the vulnerability-based approach for assessing current and future risks (TP4 and TP5). The APF presents quantitative, semi-quantitative, and qualitative methods for assessing future risks (TP5), and it discusses various quantitative and qualitative methods for evaluating and prioritizing adaptation measures (TP8). It also provides specific guidance for choosing an appropriate planning horizon for the assessment of future risks based on the policy horizon(s) of potential adaptations (TP5 and TP8). Further strengths of the APF are its emphasis on addressing uncertainties in all steps of the assessment; on considering sectoral, multi-sectoral and cross-sectoral adaptation measures; on considering no-regrets and low-regrets options in the face of large uncertainties (TP8); and on including an implementation and evaluation plan with the adaptation strategy (TP9). The APF explicitly considers some of the prerequisites of adaptation (see Sect. 2.2), such as the stakeholders' awareness of the problem and their understanding of the causes (TP5).

Two limitations of the APF are apparent. First, as a generic framework the APF cannot address the specific concerns of human health adaptation, such as providing guidance on the most appropriate methods and tools for assessing future health risks. Some authors of the APF apparently argued to produce a Technical Paper for each main sector but this was not done for reasons of time and lack of funds. Second, the APF does not advocate a tiered approach to assessing future risks where the importance of future changes in risks is assessed qualitatively before more detailed assessments are made. Hence, analysts are at risk of allocating considerable efforts to providing information that is of limited importance for policy decisions.

3.6 WHO–Health Canada Assessment Framework

The WHO, in collaboration with Health Canada, UNEP, and the WMO, has developed "Methods of assessing human health vulnerability and public health adaptation to climate change" [Kovats et al., 2003b], which aim at providing flexible instructions for conducting a human health vulnerability and adaptation assessment to climate change. The WHO–Health Canada Framework is targeted specifically at national and regional government agencies responsible for assessing the health risks associated with global climate change and for developing adaptations to them. The Framework distinguishes the following steps in assessing vulnerability and adaptation:

1. Determine the scope of the assessment.
2. Describe the current distribution and burden of climate-sensitive diseases.
3. Identify and describe current strategies, policies and measures that reduce the burden of climate-sensitive diseases.
4. Review the health implications of the potential impact of climate variability and change on other sectors.
5. Estimate the future potential health impact using scenarios of future climate change, population growth and other factors, and describe the uncertainty.
6. Synthesize the results and draft a scientific assessment report.
7. Identify additional adaptation policies and measures to reduce potential negative health effects, including procedures for evaluation after implementation.

The WHO–Health Canada Framework emphasizes a vulnerability-based approach to risk management that starts from current health risks and their determinants but it also includes model-based climate and impact scenarios when they are available. As a health-specific framework, it provides guidance on assessing vulnerability and adaptation for the most important climate-sensitive health impairments. It also makes useful recommendations on project management, and on dissemination and communication strategies.

Many of the key elements of the WHO–Health Canada Framework directly address issues raised in Sect. 2.3. In particular, the framework emphasizes the need for flexible approaches depending on the disease outcome and region of interest; the importance of stakeholder involvement throughout the assessment process; the importance of basing adaptation to climate change on the experience with managing current health risks; the importance of managing uncertainty; the value of qualitative as well as quantitative assessment approaches; the cyclical nature of risk management; and the need for a cross-sectoral perspective in assessing the health impacts of climate change and in planning effective adaptations.

The main limitations of the WHO–Health Canada Framework are as follows:

- The report presents three different assessment approaches: a 9-step risk management cycle, a 7-step approach to vulnerability and adaptation assessment, and a 3-stage approach for different levels of assessment. Readers are not informed about the relationship of these approaches, and how they might be integrated in an actual assessment. While the 7-step approach is developed in detail [see also Ebi et al., 2006a], important features of the other two approaches are largely neglected throughout the report.

- The 7-step approach considers additional adaptation measures only in the last step of the assessment. However, the portfolio of potential adaptations should already be considered early in an assessment as it determines which information is most useful from a policy perspective. For instance, decisions about adaptations with a long lead time (such as building codes to reduce the urban heat island and zoning laws to prevent building in flood-prone regions) need to be informed by an assessment of long-term risks whereas decisions about interventions with a short planning horizon can focus on the risks associated with current climate variability and extremes. (An assessment of future risks may still be relevant to inform climate change mitigation. It may also be necessary if external funding for adaptation is earmarked for interventions that reduce the impacts of anthropogenic climate change.)

- The report acknowledges that the most suitable assessment approach differs across health outcomes and regions. However, it lacks coherent information how the suitability of different approaches can be determined based on regional and disease-specific factors.

- The chapter on quantitative health impact assessment focusses on established frameworks from environmental epidemiology and concepts from comparative risk assessment that are either difficult to apply to climate change in general or that have little relevance for climate change adaptation assessments (see Sect. 4). In contrast, there is limited guidance on assessing and planning adaptations when uncertainties are too large for a quantitative assessment of future risks.

- The report lacks guidance on prioritizing potential adaptation measures in terms of their efficiency and urgency.

In summary, the WHO–Health Canada Framework is a key guidance document for adaptation policy assessments of climate change and human health. It provides the most comprehensive discussion of available methods and tools for assessing vulnerability and adaptation to climate change for the major climate-sensitive health risks. The main weakness of the WHO–Health Canada Framework is the lack of evaluation and integration of the various concepts presented. It provides only limited guidance on selecting the most suitable assessment approach and on focussing the assessment on the crucial information needs of adaptation decision-makers. Many of these issues are more systematically addressed in some of the generic assessment guidelines discussed above.

4 Conceptual frameworks from environmental epidemiology

The WHO–Health Canada Assessment Framework reviewed in Sect. 3.6 refers to Environmental Health Risk Assessment, and it presents three conceptual frameworks from environmental epidemiology as potentially useful for adaptation to climate change: DPSEEA, causal webs, and comparative risk assessment. This section summarizes a review of these (and several other) frameworks by Füssel and Klein [2004]. It also suggests an extension of the terminology underlying comparative risk assessment for application in adaptation policy assessments.

4.1 Environmental Health Risk Assessment

Environmental health risk assessment denotes the process of quantitatively or qualitatively estimating the impacts on population health of exposure to a specific hazard. It has been applied to a wide range of chemical, physical, microbiological and other hazards. Various countries have established standards for health risk assessments as part of a mandatory environmental impact assessment for a proposed activity, development, or policy. The term 'health risk assessment' is now often narrowly used in public health to quantify and extrapolate the exposure-response relationship to new exposure scenarios, or to describe a formal risk assessment that follows a specific set of guidelines. The standard process for quantitative risk assessment in environmental and occupational epidemiology consists of the following four steps [National Research Council, 1983, Nurminen et al., 1999, Department of Health and Ageing, 2002]: hazard identification, dose-response assessment, exposure assessment, and risk characterization. However, health risk assessments can be either quantitative or qualitative, and there are different legitimate approaches, depending on the particular issue of concern.

Anthropogenic climate change differs from other environmental health hazards in terms of the large spatial scale of the problem, the long time horizon, the complexity of the climatic hazard, the complexity of the relationship between climatic factors and health outcomes, and the uncertainty about future hazard scenarios (see Sect. 2.3). As a result, quantitative assessment of the health risks from (future) climate change is often hampered by the lack of reliable projections for relevant climate variables, the lack of epidemiological data on the relationship between climate exposure and health effects, and difficulties to project important non-climatic confounding factors, including behavioural aspects.

Several authors have investigated the applicability of classical risk assessment approaches to estimate the health risks associated with anthropogenic climate change [McMichael, 1993, Patz and Balbus, 1996, Haines and McMichael, 1997, Bernard and Ebi, 2001, Woodward and Scheraga, 2003]. These reviews agree that the prevailing toxicological model of environmental health where a defined exposure to a specific agent causes an adverse health outcome to identifiable exposed populations is not applicable to many climate-sensitive health impairments, in particular to indirect effects of climatic stimuli. Nevertheless, there are important lessons to be learnt from environmental health risk assessment for adaptation to climate change, such as the importance of a continuous and effective dialogue with affected stakeholders and of explicit consideration of all relevant uncertainties in the analysis.

4.2 DPSEEA framework

The DPSEEA framework (or 'health and environment cause and effect framework') is a hierarchical model linking measurable indicators to environmentally caused diseases. The framework was developed by the WHO to support decision-making on actions to reduce the burden of disease by describing environmental health problems from their root causes to the health effects, and by identifying areas for intervention [Briggs et al., 1996, WHO, 1997a,b, Briggs, 1999, Corvalán et al., 1999]. The DPSEEA framework divides the causal pathway of environmental health problems into several stages by distinguishing the following categories of indicators: **D** Driving force (anthropogenic), **P** Pressure (on the environment), **S** State (of the environment), $\mathbf{E_1}$ Exposure (of humans), $\mathbf{E_2}$ Effect (in humans), **A** Action. It also displays the various levels of actions that can be undertaken to reduce environmental health impacts. The qualitative model provided by the DPSEEA framework can be developed further into a quantitative model, or 'causal web' (see below), which may serve as a basis for environmental burden of disease assessments.

The DPSEEA framework is widely applied in environmental health. Its various stages form a logical causal chain that reflects the conventional 'linear' approach to environmental health, where the link between the exposure to a specific environmental hazard and its health effects can be described by a simple dose-response relationship. The approach is less well applicable to non-local hazards, physical risks, and health effects caused by the complex interaction of environmental and non-environmental risk factors [Briggs, 1999].

The DPSEEA framework has been adopted in proposals for monitoring health impacts of climate change [Corvalán, 2001, WHO, 2001]. Due to its limitations in representing the complex causal web that links climatic, environmental, and social factors to human health, this approach is more feasible for health effects occurring as a direct consequence of exposure to climatic stimuli (*e.g.*, heatwaves) than for those resulting from a complex interaction of climatic, ecological, and social factors (*e.g.*, vector-borne diseases). The lack of consideration of non-climatic determinants of disease in the DPSEEA framework [as presented in WHO, 2001] severely limits its applicability in an adaptation context because many potential interventions cannot be adequately represented. To be useful for the development of response strategies to climate change, the DPSEEA framework would have to be extended in a flexible way to include intermediate ecological indicators and other relevant non-climatic factors.

4.3 Causal webs and the hierarchy of causes

A causal web represents a hierarchical cause-to-effect model that comprises relationships among risk factors, and between risk factors and disease outcomes [MacMahon et al., 1960]. Causal webs aim at facilitating the comparative quantification of health risks. If the relative risk of disease from all causes and for all exposure levels is known, a causal web provides a framework for calculating the attributable and avoidable burden of disease [Murray and Lopez, 1999, Murray et al., 2003]. The term 'causal web' is now often used more narrowly to denote a 'hierarchy of causes' that distinguishes three layers of risk factors where *distal* causes operate through *proximal* and *direct* (physical) causes on the disease outcome in a cascade of causal interferences.

Causal webs, understood in a broad sense, can principally be used to represent the aetiology of any health outcome, including climate-sensitive ones. Prüss et al. [2001] suggest that they are better suited for representing the complexity of multiple interacting disease factors than more rigid indicator frameworks such as DPSEEA. Applications of the 'hierarchy of causes' framework in environmental health, however, have generally identified the three levels of health hazards and the outcome level, respectively, with the PSEE layers of the DPSEEA framework.

Causal webs have been applied to the health effects of global climate change [Kay et al., 2000, Kovats et al., 2003b]. Similar to the DPSEEA framework, however, this application may easily oversee social determinants of vulnerability to climate change and variability. The narrower interpretation of causal webs as a classification of causal factors into distal, proximal, and direct causes is not well suited for representing the complex causal structure of most climate-sensitive health effects.

4.4 Comparative Risk Assessment

Comparative risk assessment (CRA) is the systematic evaluation of potential changes in population health from altering the distribution of exposure to a risk factor or a group of risk factors. It is applied to provide an empirical basis for priority-setting in health policy. In the context of public health, the term CRA is used largely synonymous with Burden of Disease assessment, which strives to determine quantitatively how much ill-health can be attributed to particular risk factors. CRA has been applied to a large variety of risk factors, including climate change [Kay et al., 2000, Campbell-Lendrum et al., 2003, Campbell-Lendrum and Woodruff, 2006].

Campbell-Lendrum and Woodruff [2006] argue that CRA is a potentially useful approach for estimating the health risks from climate change (*i.e.*, for climate *impact* assessment) but that there are important limitations. Most importantly, application of CRA to climate change is subject to the same empirical difficulties as other quantitative health risk assessments for climate change, such as the complexity of the climate-health relationship and the difficulty of separating the effects of anthropogenic climate change and natural climate variability (see Sect. 4.1). In addition, it raises the following methodological issues [Kay et al., 2000, Füssel and Klein, 2004]:

- Definition and quantification of the climatic hazard
- Choice of counterfactual scenarios of exposure
- Consideration of long time-frames and representation of changes in non-climatic factors
- Non-monotonicity of the exposure-effect relationship
- Consideration of secondary effects of interventions
- Strength of evidence in different parts of the causal web
- Appropriate geographical resolution

Two fundamental concepts underlying CRA are 'attributable burden' and 'avoidable burden' of disease. These terms are used in CRA to characterize fractions of the current disease burden that are attributable to a specific risk factor and that could be avoided by reducing exposure to a counterfactual distribution, respectively. Recently these definitions have been generalized for situations where there is a substantial time lag between the exposure to a risk factor and the health effect [Murray and Lopez, 1999, Murray et al., 2003].

Several authors have suggested linking climate impact and adaptation assessment with CRA [*e.g.*, Kay et al., 2000, Kovats et al., 2003b, Campbell-Lendrum and Woodruff, 2006]. While these approaches have many things in common, there are also important differences. The main distinctions between 'classical' CRA and climate impact assessment are that the latter is concerned with the marginal impacts of future exposure scenarios and that the complex multifactorial causal structure of climate-sensitive health effects makes attribution to single factors difficult. Nevertheless, concepts from CRA can in principle be applied in climate *impact* assessments [McMichael et al., 2004].

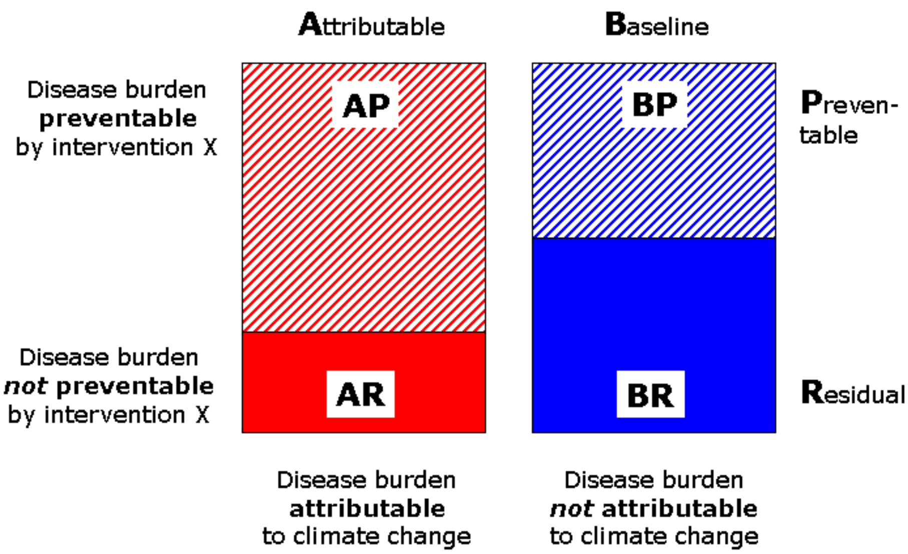
The methodological differences between *adaptation* assessments and CRA are more fundamental. Most importantly, adaptation does not define a counterfactual distribution of population exposure to climate change. Furthermore, most adaptation measures have beneficial health effects independent of anthropogenic climate change. Hence, the classical concept of avoidable burden of disease is not applicable in an adaptation context. The following section attempts to overcome this limitation by proposing an extension of the CRA terminology.

4.5 Extended CRA terminology

The extended CRA terminology presented here allows to distinguish all fractions of the disease burden that may be of interest in a quantitative climate change assessment. The basic idea is to amend the "attributable–avoidable–baseline dimension" of disease burden (that is most relevant in a mitigation context) by a "preventable–residual dimension" (that is most relevant in an adaptation context).

Fig. 1 illustrates the extended terminology in the simple case of a single time horizon, two climate scenarios (with and without climate change), and two adaptation scenarios (with and without a specific intervention). The right bar (baseline burden; $B = BP + BR$) states the burden of disease for a specific time period in the future, assuming a constant baseline climate and no intervention. The left bar (attributable burden; $A = AP + AR$) represents the additional future disease burden with climate change. Of course, reality is considerably more complex than this stylized example due to the existence of many possible response options, the dynamics of the stressor and the vulnerable system, and the varying uncertainty associated with estimates of the different disease burdens. In general, the relative size of the burden of disease attributable to climate change increases over time but the associated prognostic uncertainty is larger than for the baseline burden.

Let us illustrate the application of the extended terminology in the three main types of climate change assessments (*cf.* Sect. 2.1) with a hypothetical example. We consider a community that is already affected by heat-waves, which are expected to increase in frequency and severity due to anthropogenic climate change. This community considers the implementation of a heat watch and warning system (HWWS) that would reduce the adverse health effects of heat-waves irrespective of their attribution.



AP	preventable attributable burden
AR	residual attributable burden
BP	preventable baseline burden
BR	residual baseline burden
$A = AP + AR$	(total) attributable burden
$B = BP + BR$	(total) baseline burden
$P = AP + BP$	(total) preventable burden
$R = AR + BR$	(total) residual burden
$T = A + B = P + R$	total disease burden

Figure 1: Extended CRA terminology for describing different fractions of the burden of disease in climate change adaptation assessments [adapted from Füssel et al., 2006].

Climate impact assessments aim at determining the increase in the disease burden from future heat-waves caused by climate change in the absence of specific adaptations (denoted as 'potential impacts of climate change' in IPCC terminology). This 'total attributable burden' (A) is calculated as the difference ($A = T - B$) between the 'total disease burden' (T) for the changed climate (without intervention) and the disease burden from heat-waves in the baseline climate ('total baseline burden'; B); it can be estimated using analogue techniques or mathematical modelling [see Kovats et al., 2003b].

Climate vulnerability assessments aim at determining the expected increase in the disease burden from heat-waves caused by climate change after implementation of the HWWS (denoted as 'expected impacts of climate change' in IPCC terminology). This 'residual attributable burden' ($AR = A - AP = A + BP - P$) can, in principle, be calculated based on information from an adaptation policy assessment (see below). In practice, however, the 'residual' and/or the 'preventable attributable burden' (AR and AP, respectively) are more likely to be estimated without reference to P and BP.

Adaptation policy assessments aim at determining the total burden of disease from future heat-waves that is preventable by the HWWS irrespective of their attribution. This 'total preventable burden' (P) is independent from the burden attributable to climate change (A); the former may exceed the latter if an intervention is sufficiently effective in reducing a large baseline burden (*i.e.*, if $BP > AR$). Effectiveness of intervention studies can, in principle, provide estimates of the reduction in disease burden following the intervention for different climate states. Extrapolation of these results to the baseline climate and the climate change scenario provides estimates of the 'preventable baseline burden' (BP) and the 'total preventable burden' (P), respectively. If uncertainty for the 'preventable attributable burden' ($AP = P - BP$) is much larger than for the 'preventable baseline burden' (BP), interventions that were initially motivated by reducing the disease burden attributable to climate change may have to be evaluated primarily by their ability to reduce the baseline disease burden.

5 Summary and conclusions

Adaptation policy assessments aim at facilitating planned adaptation to the risks associated with climate change and variability (Sect. 2.1). To this end, they provide information to policy-makers on the health risks associated with climate variability and change, on the effectiveness and costs of feasible adaptations, and on ways to overcome obstacles to their implementation (Sect. 2.2). Several scientific and professional communities can provide guidance for human health adaptation assessments, including those concerned with climate change, risk management, public health, and environmental health. However, assessing and planning adaptation to the health risks associated with climate change presents several challenges that are unfamiliar to many analysts. Unfamiliar aspects include the diversity of climate-sensitive health impacts; the complex interaction of climatic, environmental, socioeconomic, demographic and behavioural factors in the causation of diseases; large uncertainties in projections of future climatic and socio-economic conditions; and the scarcity of epidemiological data on the relationship between climatic conditions, non-climatic factors and health outcomes (Sect. 2.3).

Various frameworks have been developed to provide guidance for climate change vulnerability and adaptation assessment but their application to adaptation assessments for human health has been limited so far. Most early studies of climate change and human health have followed a hazards-based (or scenario-based) approach, as described in the IPCC Technical Guidelines (Sect. 3.1), the USCSP Handbook (Sect. 3.2), and the UNEP Handbook (Sect. 3.3). These studies evaluated and extended the scientific knowledge about the relationship between climatic factors and human health and provided indispensable information on the scale of the problem and on particularly vulnerable regions. However, they offered only limited guidance to stakeholders concerned about adaptation. The main reasons are the mismatch in spatial and temporal scales between climate impact projections and typical adaptation decisions, and the limited consideration of scientific uncertainties, existing climate-related risks and socio-economic factors.

Recognizing the limitations of the hazards-based approach in providing policy-relevant knowledge to adaptation decision-makers, recent guidelines for adaptation assessment emphasize approaches that integrate adaptation to future climate change with current climatic risks and other policy concerns. The most important generic guidelines are the UKCIP Framework, which is targeted at adaptation stakeholders in industrialized countries (Sect. 3.4) and the UNDP-GEF Adaptation Policy Framework (APF), which focusses on the adaptation needs of developing countries (Sect. 3.5). The WHO–Health Canada Framework specifically addresses adaptation to the health risks of climate change and variability (Sect. 3.6).

The APF advocates a flexible assessment approach that addresses most challenges of the adaptation decision problem identified in Sect. 2.3. It provides criteria for choosing between alternative assessment approaches, and it presents and discusses a wide range of pertinent methods and tools. There is, however, only limited guidance on focussing the assessment on the most relevant information in a given decision context. The UKCIP Framework recommends an even more flexible approach to adaptation decision-making. Earlier decisions can be revised based on new information, and a multi-tiered approach helps focussing assessment efforts on the most critical impacts and/or regions. The UKCIP Framework is most useful when current climate-sensitive risks are satisfactorily controlled, and when decisions that are potentially sensitive to global climate change have already been identified by relevant decision-makers. Despite their regional foci, both the APF and the UKCIP Framework can provide valuable (and largely complementary) guidance for adaptation policy assessments in any world region. However, neither of them discusses the specific challenges of planned adaptation for human health. The WHO–Health Canada Framework presents a variety of methods and tools for assessing vulnerability and adaptation to climate change for the major climate-sensitive health risks. Compared to the generic frameworks, however, this framework provides little guidance on integrating the various concepts presented and on focussing the assessment on the key information needs of adaptation stakeholders.

Environmental health and public health have a long tradition of assessing and controlling the health risks associated with population exposure to various environmental hazards. The review of several pertinent assessment approaches and conceptual models concludes, however, that their applicability in climate change vulnerability and adaptation assessments is generally limited. The application of 'classical' approaches from (quantitative) environmental health risk assessment and management faces several difficulties due to the large geographical scope, the complex spatiotemporal structure, and the uncertainty of the hazard 'global climate change' (Sect. 4.1). Similar conclusions were obtained for the DPSEEA framework (Sect. 4.2) and the 'hierarchy of causes' model (Sect. 4.3). Application of the burden of disease concept to anthropogenic climate change raises a variety of methodological and practical issues regarding the quantification of the risk factor, the choice of the time horizon, and the consideration of uncertainties (Sect. 4.4). In principle, the concepts of 'attributable burden' and 'avoidable burden' can be applied to climate change *impact* assessments with minor adjustments. Due to the lack of a counterfactual scenario of exposure, however, the classical concept of avoidable burden cannot be applied to *adaptation* assessments. This limitation can be overcome by extending the terminology in such a way that it distinguishes fractions of disease burden according to two independent dimensions: whether it is attributable to anthropogenic climate change and whether it can be prevented by a specific intervention. The extended terminology was applied to describe the relevant fractions of the burden of disease in all main types of climate impact and adaptation assessment (Sect. 4.5).

The key conclusion of this paper is that none of the assessment guidelines reviewed here satisfactorily addresses *all* challenges of adaptation policy assessments for human health. For that reason, actual adaptation assessments should seek guidance from the different sources reviewed here, according to their respective strengths (see Table 1). Most of the pertinent guidance is already available but not necessarily in one place.

Obviously, it would be desirable to develop a unified framework for human health adaptation assessment that combines the strong points of the existing guidelines. Such a framework should describe a structured assessment approach that is flexible enough to accommodate the wide range of adaptation decision contexts. An integration of the assessment frameworks reviewed here suggests that the following steps should be included in climate change adaptation assessments for human health:

1. Scoping the project
2. Screening of current and future risks
3. Examination of the adaptation baseline
4. Review of projected climate impacts in other sectors
5. Identification of key information needs for policy decisions
6. Analysis of future risk changes
7. Evaluation of future risk changes
8. Identification of additional adaptation options
9. Evaluation and prioritization of adaptation options
10. Decision about adaptation strategy
11. Implementation of decision
12. Monitoring and evaluation of effectiveness

While the order of this list aims to resemble the sequence of steps in a typical adaptation policy assessment, it should be recalled that sophisticated adaptation policy assessments are typically multi-tiered and iterative.

The unified framework should also identify questions and criteria that help assessors choose the most appropriate assessment approach and to identify suitable methods and tools, depending on the specific circumstances of the region and health outcomes considered. For instance, a key question in many adaptation policy assessments is the choice between a hazards-based and a vulnerability-based assessment approach. The relative suitability of these approaches in a particular decision context is determined by the objective of the assessment, the type of health effects considered, the level of existing knowledge about the climate-health relationship, the policy horizon of potential adaptations, the relative magnitude of expected changes in health risks caused by climate change compared to the current disease burden, the confidence in projections of future climate change and associated health risks, and the availability of resources for the assessment. The hazards-based approach is most useful if sufficient data and resources are available to produce state-of-the-art climate scenarios at the spatial resolution relevant for adaptation, if the considered health outcome is a direct effect of population exposure to climatic stimuli, if the health risk is either not prevalent or effectively controlled at present, and if potential adaptations have a long policy horizon. Examples include changes in regional planning, town planning, and building codes aimed at reducing the adverse effects of more intense heat waves or floods in the future. In contrast, the vulnerability-based approach is more useful if climatic stress factors are closely intertwined with non-climatic factors, if current climate-related risks are unsatisfactorily controlled, if the planning horizon of adaptation actors is short, and if resources (in terms of data, expertise, time, and money) are very limited. These conditions, which are particularly prevalent in developing countries, favour policies that provide short-term benefits by controlling health risks associated with current climate variability, and that are robust across the range of plausible climate change and health impact projections.

Of course, good guidelines for adaptation assessment are only one precondition for effective prevention of climate-related deaths and diseases. In addition, resources need to be made available for conducting comprehensive vulnerability and adaptation assessments at different scales. Finally, it is crucially important to come up with the resources and the political will to implement proven public health measures to reduce the burden of disease now and in the future. Those countries and regions with a high burden of avoidable disease today are generally in the worst position to effectively manage the health risks from future climate change.

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