STEP 5: ASSESSMENT OF IMPACTS

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Impacts are estimated as the differences over the study period between the environmental and socio-economic conditions projected to exist without climate change (the future baseline), and those that are projected with climate change. This definition can be extended to include consideration of adaptation in the estimation of impacts with climate change. Up to now, few climate impact studies have paid adequate attention to adaptation. Further, many studies have assumed a fixed baseline, often failing to recognize that conditions in the future will be quite different from those at present, even in the absence of climate change. In practice, however, construction of the future baseline is often fraught with difficulties relating to the projection of highly uncertain socio-economic and environmental scenarios (cf. Section 6), and a fixed baseline at least offers a ready reference for sensitivity testing. Moreover, there are certain impact studies, particularly those involving biophysical systems, that are fully justified in using a fixed baseline (e.g., hydrological studies of pristine river catchments). These different approaches to impact assessment are illustrated in Box 7.

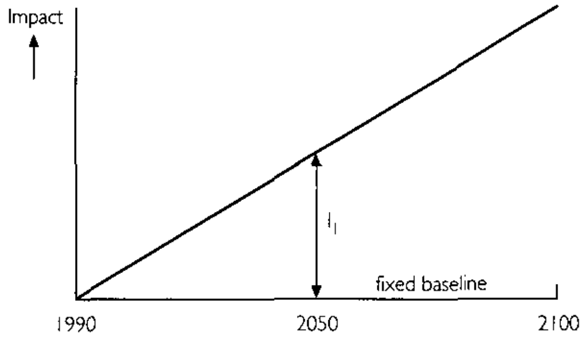
BOX 7
DIFFERING APPROACHES TO THE ASSESSMENT OF IMPACTS

The three figures illustrate schematically how differing degrees of realism in assessing impacts result from alternative assumptions about the baseline and from consideration of various types of adaptation. In Figure (a), impacts in the year 2050 (I_1) are portrayed as the cumulative effects of future climate change on an exposure unit, assuming a fixed baseline (i.e., no concomitant changes in the environmental, technological, societal and economic conditions relative to the present). This unrealistic, though readily applicable representation of the future is characteristic of many early climate impact assessments.

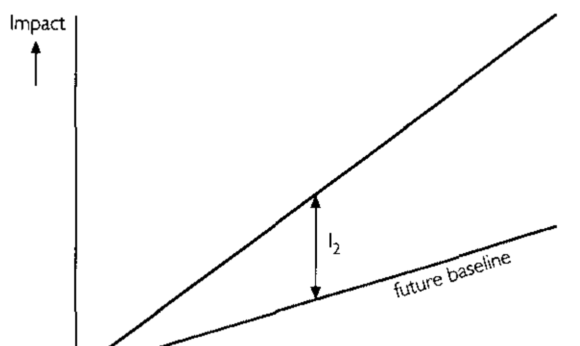
Figure (b) shows how more realism is introduced if impacts of future climate change are evaluated relative to a future baseline without climate change. The impact relative to the future baseline may be greater or, as is shown in Figure (b), less than the impact relative to the fixed baseline (I_2).

However, this approach still ignores the many adjustments and adaptations that would occur either in expectation of or in response to impacts of climate change. These are shown in Figure (c), which distinguishes between two types of adaptation: autonomous adjustment, which is implemented immediately (often unconsciously) as part of the normal package of measures available to organisms or systems for coping with climatic variability; and deliberate adaptation, which involves conscious actions to mitigate or exploit the effects of climate change. In most cases (as in Figure (c)), the objective of adaptation is to reduce the negative impacts of climate change (I_3 and I_4, respectively).

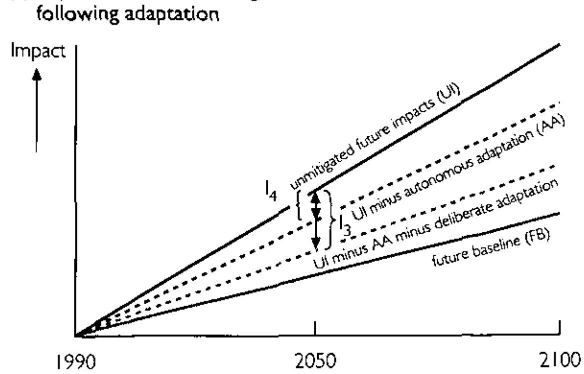
(a) Impacts of climate change relative to a fixed baseline



(b) Impacts of climate change relative to a future baseline



(c) Impacts of climate change relative to a future baseline following adaptation



The evaluation of results obtained in an assessment is likely to be influenced in part by the approach employed, and in part by the required outputs from the research. Some of the more commonly applied techniques of evaluation are described below.

7.1 Qualitative Description

An evaluation may rely solely on qualitative or semi-quantitative assessments, in which case qualitative description is the common method of presenting the findings. The success of such evaluations usually rests on the experience and interpretative skills of the analyst, particularly concerning projections of possible future impacts of climate (see, for example, Box 8). The disadvantages of subjectivity in this have to be weighed against the ability to consider all factors thought to be of importance (something that is not always possible using more objective methods such as modelling).

BOX 8
CASE STUDY: HEALTH IMPACTS OF ENVIRONMENTAL CHANGES IN HONDURAS

Background: in the past two decades the landscape of Honduras, a mountainous, tropical nation in Central America with 5.5 million inhabitants, has been transformed through overgrazing, monoculture agriculture and deforestation. In the southern region, soil dessication and erosion caused by intensive agriculture has altered the hydrological cycle, and mean temperatures have risen. Deforestation in central and northern Honduras has affected water basins and water availability. These meteorological and ecological changes have already affected the distribution of vector-borne diseases.

Problem: to examine the role of climate in influencing the distribution, abundance and transmission of vector-borne diseases (VBDs) in Honduras.

Method: the assessment was qualitative, based on expert judgement.

Testing of method: the method involved the empirical compilation of available data on recent trends in climate, land use, pesticide use, population density and prevalence of VBDs, and their geographical and temporal integration.

Scenarios: the study considered qualitative scenarios of climatic warming along with increased climatic instability, including more frequent droughts and floods, and all trends that are already being observed. Short term trends in other environmental and socio-economic factors were also examined in evaluating potential health risks.

Impacts: attention was paid to the current status and trends in a number of common VBDs, which act both directly and indirectly on humans.

Malaria: in southern Honduras, changes in land use and subsequent soil dessication and erosion during the past two decades have disrupted the hydrological cycle, leading to a recorded increase in median annual temperature in the order of 5–10°C between the early 1970s and late 1980s. This temperature increase has rendered the region too hot for anopheline mosquitoes, and the incidence of malaria has fallen. However, the concomitant aridification of the region has forced people to move away to the cities, plantations and assembly farms further north. Large areas of north-east tropical rainforest have been cleared, and migrants concentrated there tend to be non-immune to malaria. The indiscriminate use of pesticides in banana, pineapple and melon plantations has led to widespread anopheline resistance. In 1987, 20,000 cases of malaria were registered in Honduras; in 1993, 90,000 cases were recorded, of which 85 per cent were in northern regions.

Chagas' disease: 'Kissing bugs' (*Rhodnius prolixis* and *Triatoma dimitata*) are the chief vectors of Chagas' disease, and opossums, rats, armadillos, cats and dogs are among its reservoirs. Massive environmental changes such as deforestation, have altered all components in the life cycle and, deprived of habitat, sustenance and blood meals, reservoirs and bugs alike move to peri-urban areas. Chagas' (a chief cause of heart disease) is expected to increase under higher temperatures due to a shortening of insect generation time, the stimulation of blood meal seeking and an increasing frequency of active parasites, all of which amplify vector abundance and transmission.

Other VBDs: Dengue fever is increasing as *Aedes spp.* breeding sites swell in peri-urban areas. The advance of *Ae aegypti* (another vector whose maturation and generation are accelerated by warmth), plus the spread of the cold-hardy *Ae albopictus*, are increasing concern throughout Latin America, and yellow fever is in resurgence.

Indirect effects through nutrition: the common bean *(Phaseolus vulgaris)* is the principal source of protein in the diet of the poor in Latin America. Whitefly *(Bemisia tabaci)* has recently emerged as a serious vector of geminiviruses, including the bean golden mosaic geminivirus (BGMV) which has devastated bean crops in some years. Whitefly outbreaks have been exacerbated in recent years by frequent and severe droughts. Over 60 per cent of Honduran children under 10 years are malnourished, and the loss of the staple crops to vector-borne plant pathogens further stunts growth and development, reduces immunity and increases the burden of communicable illness.

Adaptation options: Intervention to control VBDs with insecticides and medication have time-limited effectiveness, and can increase vulnerability by eliminating predators of pests and selecting resistant strains. Vaccines in development hold some promise. However, anticipatory adjustments and improved management of ecosystems (forests, watersheds, mangroves) are options that may enhance the resilience to climatic stresses and improve resistance against the redistribution of opportunistic species.

Source: Almendares *et al.*, (1993)

BOX 9 CROSS IMPACTS ANALYSIS

Figure I. An interaction matrix for forest impacts (after Martin and Lefebvre, 1993)

Variable Names	Climate Change	CO_2 Enrichment	Forest microclimate	Fire	Pathogens	Tree birth	Tree growth	Tree death	Forest area	Nutrient cycling	Trace gas emissions	Chemistry	Aquatic ecosystems	Wildlife	Forest products industry	Fisheries	Recreation	Economics	*Row sum (driving power)*
Climate Change			I	I		I	I	I					I	I			I		8
CO_2 Enrichment	I		I				I	I					I						5
Forest microclimate				I	I	I	I	I		I	I	I	I	I			I		11
Fire					I	I	I	I	I	I	I			I			I		9
Pathogens						I	I	I											3
Tree birth									I					I	I	I			4
Tree growth				I		I			I	I	I			I	I		I		8
Tree death				I		I			I	I	I		I	I	I		I		9
Forest area	I			I							I			I	I		I		6
Nutrient cycling						I	I	I			I		I	I					6
Trace gas emissions												I							1
Chemistry	I					I	I	I											4
Aquatic ecosystems						I											I		2
Wildlife						I	I	I		I	I						I		6
Forest products industry						I	I	I										I	4
Fisheries													I					I	2
Recreation						I	I	I					I	I				I	6
Economics																			0
Column sum (dependency)	3	0	2	5	2	12	10	10	4	5	7	2	7	9	4	1	9	3	

Cross impacts analysis (Holling, 1978) is a method of highlighting and classifying the relationships between key elements of a system. It entails identifying the pertinent variables of the system, and entering these into an interaction matrix, which represents the relationships between the different variables. If one variable exerts a direct influence on the other variable, an entry is made in the appropriate cell of the matrix. The entry can simply indicate presence or absence of an influence (a special case of cross impacts analysis termed structural analysis), or it can be assigned a quantitative weight to indicate the strength of the influence. Additionally, some measure of uncertainty in the relationship may also be given (e.g., see Clark, 1986). By summing the cell values by rows and columns, a measure is obtained of the driving power or influence of a variable (row sums) and dependency of a variable (column sums).

An example of a cross impacts (structural) analysis for impacts of climate change on forests is given in Figure I (Martin and Lefebvre, 1993). Only the presence or absence of an influence are indicated. For example, climate change is shown to influence forest microclimate, fire, tree birth, tree growth, tree death, aquatic ecosystems, wildlife and recreation: a total driving power (row sum) of 8. Similarly, pathogens are influenced by forest microclimate and fire, giving a total dependency (column sum) of 2.

Variables can now be categorized into four types: autonomous variables (weak drivers and weakly dependent), result variables (weak drivers and strongly dependent), relay variables (strong drivers and strongly dependent) and forcing variables (strong drivers and weakly dependent). These can readily be distinguished by plotting the row and column totals on a driving power/dependency graph (Figure II). In this example, forest microclimate appears to be more of a forcing variable than climate change from the standpoint of the forest. Moreover, by these criteria, tree growth and tree death should constitute good indicators of climate change and could be usefully monitored to determine the future of the forest.

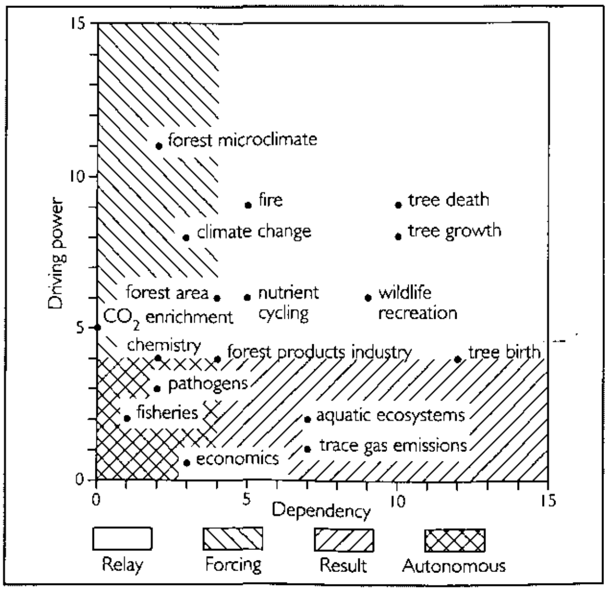
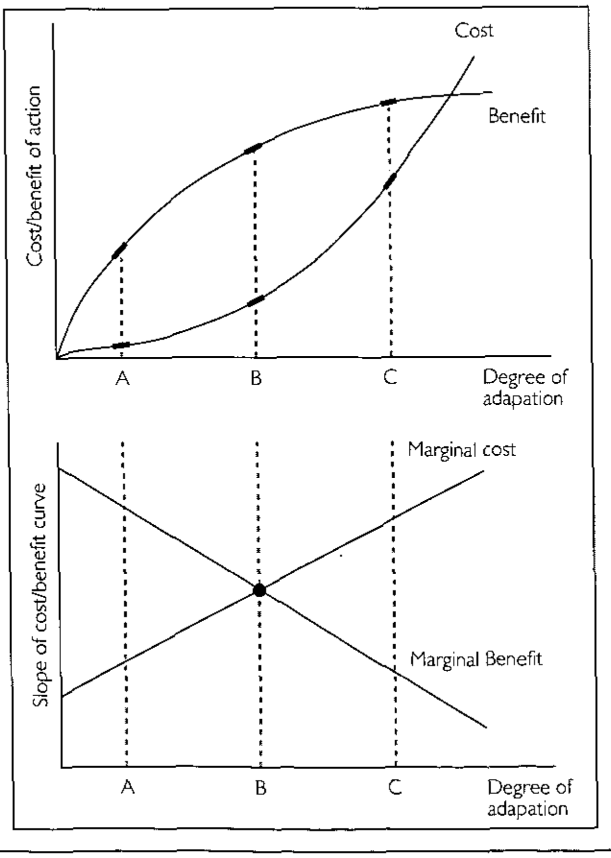


Figure II. Outcomes of the forest impacts structural analysis (after Martin and Lefebvre, 1993)

BOX 10
COST-BENEFIT ANALYSIS

Cost-benefit analysis has the specific objective of evaluating an anticipated decision or range of decision responses. For example, in considering the costs and benefits of an adaptation strategy, a cost-benefit analysis might seek to evaluate a question facing a decision maker: 'Do the benefits of a given level of adaptation outweigh the costs of its implementation?' The benefits of this action are the avoided damages (i.e., costs) of impacts of climate change (evaluated, for instance, using models of the type described in Section 4.2.2).

The problem can be illustrated in a simple diagram (see figure). In the upper graph, the degree of adaptation is expressed as two lines: one representing the costs of adaptation and the other the benefits (avoided costs) accruing from this action. Both lines show increases with increasing levels of adaptation, but the growth in costs accelerates, while the growth in benefits diminishes. Characteristically, the costs of minimal adaptation are small while the benefits are high (e.g., at point A), but as the level of adaptation increases, so the additional or marginal costs increase, while the marginal benefits decline. These are the slopes of the two lines in the upper graph, plotted as straight lines in the lower graph. Economic analysis generally concludes that the optimal result is where the marginal cost and marginal benefit of the change are equal (point B on the graph). To the left of point B further action is beneficial, because the additional (marginal) benefits secured exceed the additional (marginal) costs. Further adaptation beyond point B produces an unfavourable cost-benefit ratio (e.g., at point C) and is therefore not justified.



A more formal method of organizing qualitative information on impacts of climate change, cross impacts analysis, is illustrated in Box 9.

7.2 Indicators of Change

A potentially useful method of evaluating both the impacts of climate change and the changes themselves is to focus on regions, organisms or activities that are intrinsically sensitive to climate. For example, climate change might affect the altitude at which certain temperature-limited vector-borne diseases are found, and high altitude sites in Kenya, Rwanda, Costa Rica and Argentina have been suggested as potential foci for monitoring both of the vectors themselves, and of the populations at risk (Haines *et al.*, 1993). Similarly, changes in plant behaviour may indicate that certain critical thresholds of temperature change have been approached or exceeded. For instance, an increasing frequency of events where plants fail to flower may suggest that the chilling (vernalization) requirements of the plant have not been fulfilled. Another example is low-lying coastal zones at risk from inundation due to rising sea level, and the vulnerable populations located in such regions.

7.3 Compliance to Standards

Some impacts may be characterized by the ability to meet certain standards which have been enforced by law. The standards thus provide a reference or an objective against which to measure the impacts of climate change. For example, the effect of climate change on water quality could be gauged by reference to current water quality standards.

7.4 Costs and Benefits

Perhaps the most valuable results that can be provided to policy makers by impact assessments are those which express impacts as potential costs or benefits. Methods of evaluating these range from formal economic techniques such as cost-benefit analysis to descriptive or qualitative assessments.

Cost-benefit analysis is often employed to assess the most efficient allocation of resources (see Box 10). This is achieved through the balancing or optimization of various costs and benefits anticipated in undertaking a new project or implementing a new policy, accounting for the reallocation of resources likely to be brought about by external influences such as climate change. The approach makes explicit the expectation that a change in resource allocation is likely to yield benefits as well as costs, a useful counterpoint to many climate impact studies, where negative impacts have tended to receive the greatest attention.

Whatever measures are employed to assess costs and benefits, they should employ a common metric. Thus, for example, where monetary values are ascribed, this should be calculated in terms of net present value, i.e. the discounted sum of future costs and benefits. The choice of discount rate used to calculate present value will vary from nation to nation depending on factors such as the level of economic development, debt stock and social provision. Moreover, the depreciation of capital assets with time, which also varies from country to country, should be explicitly considered in the calculations.

Formal cost-benefit analysis proceeds on the basis of applying a single money metric for costs and benefits as far as is possible and credible. In the context of global warming, the relevant costs are the costs of mitigation and adaptation. These will tend to be expressed in terms of marketed resources such as labour and capital costs. The benefits of mitigation and adapta-

BOX 11 CASE STUDY: EFFECTS OF CLIMATE CHANGE ON NATURAL TERRESTRIAL ECOSYSTEMS IN NORWAY

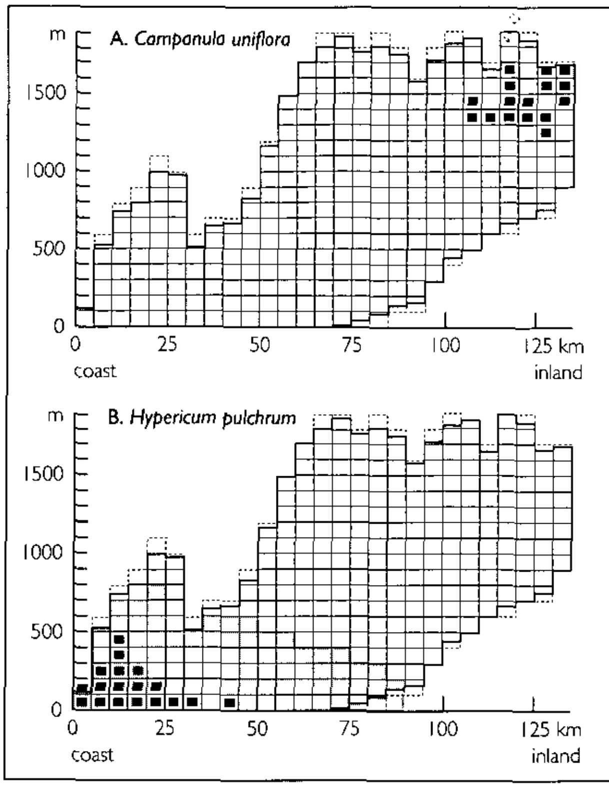
Problem: the objectives of this assessment were to examine the probable patterns of ecological change in Norway under a changed climate regime, with a particular emphasis on identifying plant species and communities sensitive to or at risk from climate change.

Methods: in part descriptive, based on expert judgement, and in part using correlative models of species distribution. All methods examined the potential impacts of climate change as defined in a specific climatic scenario for Norway.

Testing of methods/sensitivity: correlative models are based on the spatial coincidence of vegetation species and climatic variables under present-day climate. They are very simple to apply, but have the disadvantage that they do not provide an ecophysiological explanation of the observed plant distributions, although they usually represent hypotheses about which factors control or limit those distributions. The models can really only be tested against palaeoecological evidence of plant distributions from previous cool or warm periods, where the contemporary climatic information is derived from independent sources (e.g., insect evidence).

Scenarios: a seasonal scenario for an equivalent doubling of CO_2 was used, based on a subjective composite of results from several GCMs for the Norwegian region.

Impacts: the effects of climate change on species distribution were estimated using a narrow west-east transect through central Norway, giving altitude on the vertical axis and distance from the Atlantic coast on the horizontal axis. Dashed boxes indicate variations in altitude at site locations within the transect. Figures A and B illustrate the sensitivity of two species: *Campanula uniflora* (a rare alpine and continental species) and *Hypericum pulchrum* (a frost sensitive coastal species) to the climate changes described by the scenario. Solid squares indicate the current and shaded squares the predicted distribution of a species. The analysis suggests that rare northern or Alpine species may be threatened by extinction (Figure A), both due to shifts in climate and to changes in snow cover and runoff. Temperate and oceanic zone species would be favoured under the changed climatic regime (Figure B), but their colonization could be delayed by anthropogenic or natural barriers.



Source: Holten and Carey (1992)

tion are expressed in terms of avoided warming damages. In turn, these damages may show up in terms of market values—lost crops, forest damage etc., and in non-market values—changes in human health, changes in amenity and biodiversity, for example. As far as what counts in assessing damages, the distinction between market and non-market values is immaterial: both contribute to human well-being, which is the ultimate yardstick of cost-benefit assessments. In practice, both types of value raise complex issues. Market values may not, for example, represent the true value of resources to a given economy, e.g., in the presence of taxes or subsidies or if environmental costs are neglected. In this case, they have to be adjusted to secure their 'shadow' values which measure the cost of the damage to society as a whole. Non-market values have to be elicited by direct and indirect methods such as contingent valuation, hedonic property and wage models, travel cost measures, etc. The resulting estimates should, like shadow market values, reflect the underlying willingness of individuals to pay for the commodity, asset or service that is at risk.

There is extensive economic literature on both the methodologies for valuing non-market damages, and on empirical estimates (for an overview, see Pearce, 1993).

7.5 Geographical Analysis

One common feature of the different approaches to climate impact assessment is that they all have a geographical dimension. Climate and its impacts vary over space, and this pattern of variation is likely to change as the climate changes. These aspects are of crucial importance for policy makers operating at regional, national or international scale, because changes in resource patterns may affect regional equity, with consequent implications for planning.

Thus the geographical analysis of climate changes and their impacts, where results are presented as maps, has received growing attention in recent years. This trend has been paralleled by the rapid development of computer-based geographical information systems (GIS), which can be used to store, analyse, merge and depict spatial information.

The applications of GIS in climate impact analysis include:

- Depicting patterns of climate (past, present or projected).
- Using simple indices to evaluate the present-day regional potential for different activities based on climate and other environmental factors (e.g., crop suitability, energy demand, recreation, water resources). The indices can then be compared with observed patterns of each activity as a validation test.

- Mapping changes in the pattern of potential induced by a given change in climate. In this way the extent and rate of shift in zones of potential can be evaluated for a given change in climate.
- Identifying regions of particular sensitivity and vulnerability to climate, which may merit more detailed examination (for example, regions where, on the basis of the map analysis, it may be possible, under a changed climate, to introduce new crop species).
- Considering impacts on different activities within the same geographical region, so as to provide a compatible framework for comparison and evaluation (e.g., to consider the likely competing pressures on land use from agriculture, recreation, conservation and forestry under a changed climate).

A simple ecological example is given in Box 11. As computer power improves, the feasibility of conducting detailed modelling studies at a regional scale has been enhanced. The main constraint is on the availability of detailed data over large areas, but sophisticated statistical interpolation techniques and the application of stochastic weather generators to provide artificial climatological data at a high time resolution, may offer partial solutions.

7.6 Dealing with Uncertainty

Uncertainties pervade all levels of a climate impact assessment, including the projection of future GHG emissions, atmospheric GHG concentrations, changes in climate, future socio-economic conditions, potential impacts of climate change and the evaluation of adjustments. There are two methods which attempt to account for these uncertainties: uncertainty analysis and risk analysis.

7.6.1 Uncertainty analysis

Uncertainty analysis comprises a set of techniques for anticipating and preparing for the impacts of uncertain future events. It is used here to describe an analysis of the range of uncertainties encountered in an assessment study. These arise from two sources, here referred to as 'errors' and 'unknowns'.

Errors may arise from several sources, including measurement error, paucity of data and inadequate parameterization or assumptions. Unknowns include alternative scenarios, or the omission of important explanatory variables. The maximum range of uncertainty is the product of the individual uncertainties. The upper and lower bounds of these may be highly improbable, so more useful alternatives are confidence limits (e.g., 5 or 95 percentiles), which can be computed by studying the probability of uncertainties propagating, using methods such as Monte Carlo analysis (for energy and GHG emissions examples, see Edmonds *et al.*, 1986 and de Vries *et al.*, 1994; for a health impacts example, see Martens *et al.*, 1994; for an agricultural example, see Brklacich and Smit, 1992). These percentiles are often used as upper and lower estimates of an outcome, with the mean or median outcome used as the 'best' or 'central' estimate. The quantification of uncertainty arising from inadequate parameterizations or assumptions is more problematic, however, as probabilities cannot readily be assigned to different choices.

7.6.2 Risk analysis

Risk analysis deals with uncertainty in terms of the risk of impact. Risk is defined as the product of the probability of an event and its effect on an exposure unit. It has been argued that future changes in average climate are likely to be accompanied by a change in the frequency of extreme or anomalous events, and it is these that are likely to cause the most significant impacts (Parry, 1990). Thus there is value in focusing on the changing risk of climatic extremes and of their impacts. This approach can then be helpful in assessing the potential risk of impact relative to predefined levels of acceptable or tolerable risk. It is important to stress, however, that while occurrence probabilities of hypothetical climatic events are relatively straightforward to compute, it is not generally possible to ascribe any degree of confidence to probabilities of future impacts.

In those disciplines that inherently deal with probabilities, frequencies and statistical information to characterize natural hazards (floods, storms, waves, earthquakes, streamflow) and design criteria for control structures, the application of risk and uncertainty analysis is a central feature of decision-making. Extensions of commonly used methods that have evolved for dealing with historical climatic variability can be employed for climate change impact studies, especially in the important areas of hydrology, water management and shore protection (Stakhiv *et al.*, 1991; 1993).

Another form of risk analysis—decision analysis—is used to evaluate response strategies to climate change. It can be used to assign likelihoods to different climatic scenarios, identifying those response strategies that would provide the flexibility, at the least cost (minimizing expected annual damages), that best ameliorates the anticipated range of impacts (for a water resources example, see Fiering and Rogers, 1989).

A method for evaluating responses to rare and extreme hydrological events—multiobjective risk partitioning—has been developed by Haimes and Li (1991), which combines both risk and uncertainty of individual events with a decision tree framework, in order to identify solutions that best accommodate the range of uncertainty.