STEP 2: SELECTION OF THE METHOD

4

A variety of analytical methods can be adopted in climate impact assessment. These range from qualitative descriptive studies, through more diagnostic and semi-quantitative assessments to quantitative and prognostic analyses. Any single impact assessment may contain elements of one or more of these types, but whatever methods are selected, these should be clearly set out and explained. Transparency in the description of the methods, models and assumptions is essential both to evaluate the credibility of the different approaches and to compare between different assessments. Four general methods can be identified: experimentation, impact projections, empirical analogue studies and expert judgement.

4.1 Experimentation

In the physical sciences, a standard method of testing hypotheses or of evaluating processes of cause and effect is through direct experimentation. In the context of climate impact assessment, however, experimentation has only a limited application. Clearly it is not possible physically to simulate large-scale systems such as the global climate, nor is it feasible to conduct controlled experiments to observe interactions involving climate and human-related activities. Only where the scale of impact is manageable, the exposure unit measurable, and the environment controllable, can experiments be usefully conducted.

Up to now most attention in this area has been on observing the behaviour of plant species under controlled conditions of climate and atmospheric composition (e.g., see Strain and Cure, 1985; van de Geijn *et al.*, 1993). In the field such experiments have mainly comprised gas enrichment studies, employing gas releases in the open air, or in open or closed chambers including greenhouses. The former experiments are more realistic, but are less amenable to control. The chamber experiments allow for climatic as well as gas control, but the chambers may introduce a new set of limiting conditions which would not occur in reality. The greatest level of control is achievable in the laboratory, where processes can be studied in more detail and can employ more sophisticated analyses.

The primary gases studied have been carbon dioxide, sulphur dioxide and ozone, all of which are expected to play an interactive role with climate in future plant growth and productivity. Both temperature and water relations have also been regulated, to simulate possible future climatic conditions. To date, there have been experiments with agricultural plants (both annual and perennial crops), crop pests and diseases (often in conjunction with host plants), trees (usually saplings, but also some mature species), and natural vegetation species and communities (where aspects of competition can be studied). Controlled experiments have also been reported on freshwater ecosystems (to study effects on water quality and the food chain) and soils (examining decomposition rates, nutrient leaching and microbial activity).

There are other sectors in which experimentation may yield useful information for assessing impacts of climatic change. For instance, building materials and design are continually being refined and tested to account for environmental influences and for energy-saving. Information from these tests may provide clues as to the performance of such materials, assuming they were widely employed in the future, under altered climatic conditions.

The information obtained from experiments, while useful in its own right, is also invaluable for calibrating models which are to be used in projecting impacts of climatic change (see below).

4.2 Impact Projections

One of the major goals of climate impact assessment, especially concerning aspects of future climatic change, is the prediction of future impacts. A growing number of model projections have become available on how global climate may change in the future as a result of increases in GHG concentrations (e.g., see IPCC, 1990a; 1992a). These results, along with scientific and public concerns about their possible implications, have mobilized policy makers to demand qualitative assessments of the likely impacts within the time horizons and regional constraints of their jurisdiction.

Thus, a main focus of much recent work has been on impact projections, using an array of mathematical models to extrapolate into the future. In order to distinguish them from 'climate models', which are used to project future climate, the term 'impact model' has now received wide currency.

At the start of any climate impact assessment, researchers are commonly confronted with an important choice with regard to impact models—either to adopt existing models or to develop new models. Bearing in mind that most assessments have severe time and resource constraints, the most sensible strategy for model selection is first, to conduct a rigorous survey of existing models that are applicable to the issue being investigated. This exercise is best conducted by experienced modellers, but some information for non-specialists can also be provided by international organizations, who can advise on suitable models or even supply them directly. Examples of these can be found in the following sections.

The second important step is to examine a model's data needs. Without suitable input data, even the most perfect of models cannot be used. If there are suitable data, the models can be tested according to the procedures described in Section 5.3. If input data are not available, or inadequate, then for some applications it may be necessary or desirable to collect the appropriate information (cf. Section 5.2).

Finally, if suitable models cannot be identified, then it may become necessary to develop new models. In some regions with appropriate data it may be possible, in quite a short time, to construct simple statistically-based models which are robust enough to be applicable to climate change problems. This has often been the practice in many less developed countries, where access to more sophisticated models is sometimes limited, and the development of such models may be constrained by poor data quality and lack of modelling expertise. Even in developed countries, however, in the context of an impact assessment study, construction of these models from first principles is likely to be too time and resource intensive and is rarely undertaken. It is more common for model development to involve refinements of existing models which take account of altered conditions under a changing climate. For example, many crop growth models developed for yield prediction under present-day conditions, have been modified for climate impact studies to account for the effects of increasing CO_2 on carbon uptake and water use (assumed constant in conventional applications).

Some of the specific procedures for projecting future impacts are described in Section 6. Here, the major classes of predictive models and approaches are described. It is convenient, in categorizing impact models, to follow the hierarchical structure of interactions that was introduced in Section 2.3.1. Direct effects of climate are usually assessed using biophysical models, while indirect or secondary effects are generally assessed using a range of biophysical, economic and qualitative models. Finally, attempts have also been made at comprehensive assessments using integrated systems models.

4.2.1 Biophysical models

Biophysical models are used to evaluate the physical interactions between climate and an exposure unit. There are two main types: empirical-statistical models and process-based models. The use of these in evaluating future impacts is probably best documented for the agricultural sector (e.g., see WMO, 1985), the hydrological aspects of water resources (e.g., WMO, 1988) and ecosystems (e.g., Bonan, 1993), but the principles can readily be extended to other sectors.

Empirical-statistical models are based on the statistical relationships between climate and the exposure unit. They range from simple indices of suitability or potential (e.g., identifying the temperature thresholds defining the ice-free period on important shipping routes), through univariate regression models used for prediction (e.g., using air temperature to predict energy demand) to complex multivariate models, which attempt to provide a statistical explanation of observed phenomena by accounting for the most important factors (e.g., predicting crop yields on the basis of temperature, rainfall, sowing date and fertilizer application).

Empirical-statistical models are usually developed on the basis of present-day climatic variations. Thus, one of their major weaknesses in considering future climate change is their limited ability to predict effects of climatic events that lie outside the range of present-day variability. They may also be criticized for being based on statistical relationships between factors rather than on an understanding of the important causal mechanisms. However, where models are founded on a good knowledge of the determining processes and where there are good grounds for extrapolation, they can still be useful predictive tools in climate impact assessment. Empirical-statistical models are often simple to apply, and less demanding of input data than process-based models (see below).

Process-based models make use of established physical laws and theories to express the interactions between climate and an exposure unit. In this sense, they attempt to represent processes that can be applied universally to similar systems in different circumstances. For example, there are well-established methods of modelling leaf photosynthesis which are applicable to a range of plants and environments. Usually some kind of model calibration is required to account for features of the local environment that are not modelled explicitly, and this is generally based on empirical data. Nevertheless, there are often firmer grounds for conducting predictive studies with these process-based models than with empirical-statistical models. The major problem with most process-based models is that they generally have demanding requirements for input data, both for model testing and for simulating future impacts. This tends to restrict the use of such models to only a few points in geographical space where the relevant data are available. In addition, theoretically-based models are seldom able to predict system responses successfully without considerable efforts to calibrate them for actual conditions. Thus, for example, crop yields may be overestimated by process-based yield models because the models fail to account for all of the limitations on crops in the field at farm level.

During the past twenty years, or so, there has been an enormous proliferation of process-based models, which have developed to describe many different kinds of system. Many of these have been applied in climate impact assessment, but the documentation of these models is often poor or difficult to obtain, computer code may not be readily available, and the selection of appropriate models for a particular problem or region can be very difficult. Recently, efforts have been made to organize model intercomparison exercises, (e.g., for computation of evapotranspiration; Smith, 1992), to coordinate the standardization of model structure (e.g., within the International Benchmark Sites Network for Agrotechnology Transfer, IBSNAT), and to make generic or alternative models available to users in a single package (e.g., CROPWAT, a computer program for irrigation planning and management available from FAO along with a climate data base of 3261 stations in 144 countries; FAO, 1992a; and the agricultural decision support system for a range of crops supplied by IBSNAT; IBSNAT, 1989).

New techniques are also being developed to simplify the results of process-based simulation models using statistical techniques (Buck *et al.*, in press). The idea of this approach is to fit statistical response surfaces to numerous outputs derived from simulation models. Applied with care, this method can provide a rapid means of exploring the sensitivity of the more detailed simulation models without having to run the models themselves.

4.2.2 Economic models

Economic models of many kinds can be employed to evaluate the implications of climate change for local and regional economies. To simplify their classification, it is useful to distinguish between three types of economic model, according to the approach used to construct them, and three scales of economic activity that different model types can represent.

4.2.2.1 Types of economic model

Three broad classes of economic model can be identified: programming, econometric and input-output models.

Programming models have an objective function and constraints. The objective function represents the behaviour of the producer (e.g., profit maximizing or cost minimizing). If the objective function and constraints are linear, the model is known as a Linear Programming (LP) model. If the objective function is quadratic and the constraints linear, the model is a Quadratic Programming (QP) model. If either the objective function or the constraints are nonlinear, the resulting model is a Nonlinear Programming model. However, LP models can also incorporate nonlinear relations (for example, technical relations) in a piecewise manner. Programming models can also be of the partial equilibrium type, i.e., they determine production (supply) and demand simultaneously. They are usually calibrated to a set of data in a given year. In this sense they are empirically based. Programming models can be static or dynamic. An example of the application of LP models to assessing impacts of climate change is the study by Adams *et al.* (1989) on U.S. agriculture.

Econometric models consist of supply and/or demand functions which use as independent variables prices and a number of 'technical' variables, and usually include time to represent those parts of the economy that undergo steady change. Like programming models, these models also have their parameters numerically quantified, but econometric models differ substantially in their structure from programming models. Conventionally, econometric models do not state any decision rules. However, in the last decade a new set of econometrically specified models has emerged: the so-called dual models. These assume decision rules such as profit maximizing or cost minimizing of producers and utility maximizing or expenditure minimizing of the consumer. In these cases, data fitting is usually done by statistical methods (regression analysis) or a simple calibration procedure is used. The bulk of econometric models are static (including those that embed a time trend), whilst among the few examples of dynamic models are the so-called adaptive models.

Input-output (IO) models are developed to study the interdependence of production activities. The outputs of some activities become the inputs for others, and vice versa (Lovell and Smith, 1985). These input-output relationships are generally assumed to be constant, which is a weakness of the approach, since re-organization of production or feedback effects (such as between demand and prices) may change the relationships between activities. This is of particular concern when projecting production activities beyond a few years into the future. More recently, dynamic versions of IO models have been developed, but these still lack many of the dynamic aspects of economic behaviour. Nonetheless, the approach is relatively simple to apply and the data inputs are not demanding. Moreover, these models are already in common usage as planning tools. Examples of their application in climate impact assessment include studies of possible impacts of climate change on the economy of Saskatchewan (Williams *et al.*, 1988—see Box 12 on page 37) and on economic activity in the states of Missouri, Iowa, Nebraska and Kansas (the MINK study) in the USA (Rosenberg, 1993—see Box 13, on page 38).

4.2.2.2 Scales of model application

Three scales of economic activity are commonly represented by economic models: firm-level, sector-level and economy-wide.

Firm-level models depict a single firm or enterprise (i.e., a decision unit for production). These are often programming models but are rarely of the econometric type, due to constraints on available information about firms. Typical examples include farm level simulation models, which attempt to mirror the decision processes facing farmers who must choose between different methods of production and allocate adequate resources of cash, machines, buildings and labour to maximize returns (e.g., Williams *et al.*, 1988). Such models may also require data on productivity, and it is this which constitutes the entry point for potential linkages with the outputs from biophysical models. Model outputs include farm-level estimates, for example, of income, cash flow and resource costs for obtaining selected production plans. These models are sometimes referred to as microsimulation models.

Sector-level models encompass an entire sector or industry. They can be programming models or of the econometric type, to depict production. For climate change studies, these models should be of a partial equilibrium type, to include demand so that price changes are generated as well. It is quite common for such models to consider a firm as representative of the average of the entire sector under study. Such models are then similar to firm-level models, but require aggregation and assumptions about average technical relations. Some sector-level models are also of the IO type, and have supply and demand included. These models usually have no or very few links to developments in the rest of the economy.

Economy-wide models, sometimes referred to as macroeconomic models (which are actually a large subset of this class), link changes in one sector to changes in the broader economy, dealing with all economic activities of a spatial entity like a country, a region within a country or a group of countries. Typical economy-wide models for climate impact assessment include all types of general equilibrium (GE) models and IO models. Most GE models belong to the group of dual econometric models, but there are also programming models among them. The distinctive feature of GE models is that they determine endogenously (equilibrium) prices which clear the market in the same way as partial equilibrium models. However, unlike partial equilibrium models, GE models encompass all economic activities of the region. The static form of the GE model is the computable general equilibrium (CGE) model. Some of the studies of climate impacts conducted to date with CGE models have used as inputs the results of studies of sectoral impacts. For example, the results of an agricultural impacts study by Adams *et al.* (1989), along with results from studies on coasts (related to sea level rise) and electricity demand, were used as inputs to a general equilibrium model of the US economy to assess the wider implications in all sectors of the economy (Scheraga *et al.*, 1993). There are also dynamic GE models, which can treat the evolution of an economy through time, ensuring at each time step that the markets are in equilibrium. For example, a (recursively) dynamic GE model of global food trade, the Basic Linked System, has been used to study the potential effects of climatic change on global food supply, using information on potential yield changes of major crops taken from crop modelling studies conducted at 112 sites in 18 countries (Rosenzweig and Parry, 1994).

Economic models are the only credible tools for deriving meaningful estimates of likely effects of climate change on measurable economic quantities such as income, GDP, employment and savings. However, great care is required in interpreting the results. Specifically, caution must be exercised in using any of the measures of economic activity as indicators of social welfare. Potentially more serious, however, is the failure of most models (exceptions include the models of Cline (1992) and Fankhauser (1993)) to account for non-market effects of climate change. For example, many inputs to production are directly affected by climate change (e.g., land and water) but are not contained in most macroeconomic models. Economic models are also widely used to consider the relative cost-effectiveness of mitigation and adaptation options that are proposed to ameliorate the adverse impacts of climate change, along with associated economic, social and environmental impacts of these options. Some of these points are further addressed below in relation to integrated models.

4.2.3 Integrated systems models

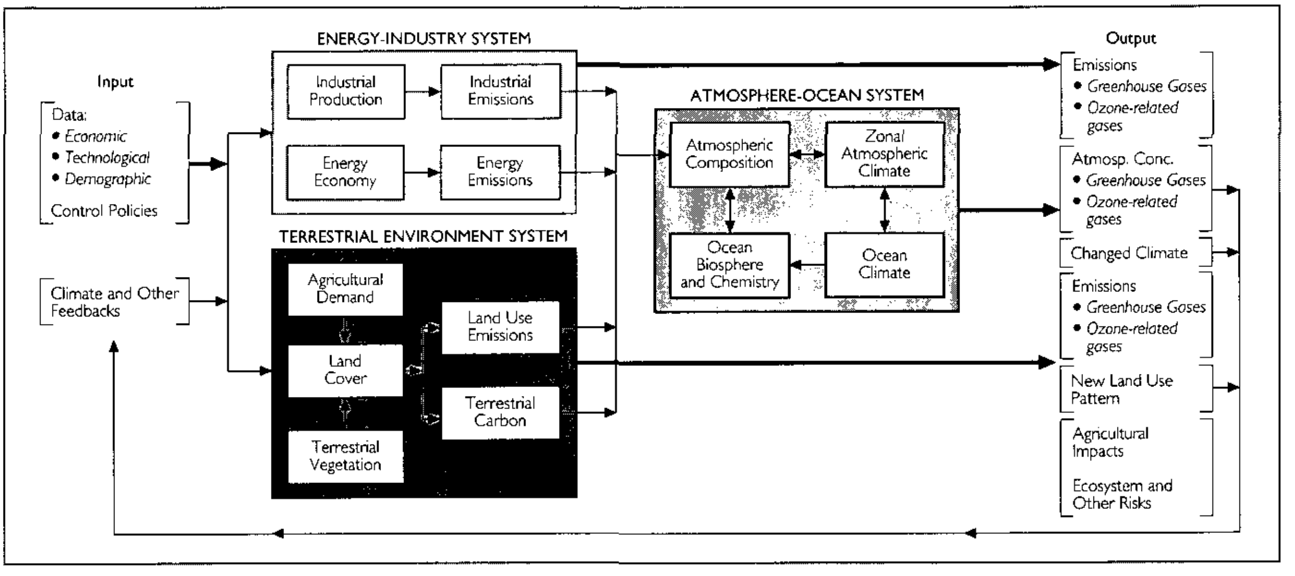
The issue of greenhouse gas-induced climate change now assumes a high profile in national and international policy making. In order to inform policy, however, it is necessary to identify and address all of the different components of the problem. This has been the motive force behind recent efforts to integrate the causes, impacts, feedbacks and policy implications of the 'greenhouse problem' within a modelling framework. Two

BOX 1
AN APPLICATION OF IMAGE 2.0
A GLOBALLY INTEGRATED SYSTEMS MODEL

Background: IMAGE 2.0 is a global model designed to provide a science-based overview of climate change issues to support the national and international evaluation of policies (Alcamo, 1994).

Model: IMAGE 2.0 consists of three fully linked components: energy-industry, terrestrial environment and atmosphere-ocean (see figure). Dynamic calculations are performed for a one hundred year time horizon and the model is embedded in a geographical information system.

increased water use efficiency, temperature responses of plant photosynthesis and respiration, temperature and soil water responses of decomposition processes and climate-induced changes in vegetation and agricultural patterns and consequent changes in land cover. A unique feature of the model is its ability to relate changes in land cover to the demand for agricultural land. This component is driven by regional population and economic activity. The agricultural demands are combined with regional potential crop productivity and distribution to determine the amount of agricultural land required. If this exceeds the current amount, simple rules are applied to determine the expansion of agricultural land into areas currently under other land cover types (e.g., using the nearest areas with the highest potential productivity first).



The energy-industry set of models are used to compute the emissions of greenhouse gases in each region as a function of energy consumption and industrial production. The terrestrial environment component simulates land use and land cover dynamically through time over a 0.5° x 0.5° latitude longitude grid, employing these changes to determine greenhouse gas emissions from the terrestrial biosphere to the atmosphere. The atmosphere-ocean set of models computes the build-up of greenhouse gases in the atmosphere and the resulting change in climate. Emissions from the energy-industry and terrestrial environment components are combined and used to determine the uptake of carbon by the oceans and the atmospheric gas and aerosol composition. The climatic response to atmospheric forcing is determined with an atmospheric energy balance model, which is used in conjunction with information from GCMs to provide regional climate change scenarios.

Application: determining feedback processes in the response of the terrestrial carbon cycle to climate change.

Methods: the terrestrial environment component of IMAGE 2.0 was used to compute the carbon fluxes between the terrestrial biosphere and the atmosphere. The model can simulate the effects of feedback processes occurring under increased atmospheric CO_2 concentrations and a changing climate: the enhancement of plant growth (CO_2 fertilization) and

Scenarios: the projection horizon is 1970 to 2050. The IPCC 'Best Estimate scenario' (IS92a) is used to define the socio-economic projections: a world population increase of 93 per cent and GNP increase of 134 per cent by 2050. The climatic scenario is based on the Geophysical Fluid Dynamics Laboratory (GFDL) 2 x CO_2 equilibrium experiment (Manabe and Wetherald, 1987), assumed to be concurrent with an equivalent-CO_2 concentration of 686 ppm by 2050 (570 ppm for CO_2 alone) relative to 1970.

Impacts: changes in climate and in water use efficiency induce shifts in vegetation patterns relative to 1970. CO_2-fertilization decreases net carbon emissions to the atmosphere while changed decomposition rates increase emissions, though regionally there are large differences. Changes in the global balance between photosynthesis and respiration make little net difference. Neglecting land use changes, the terrestrial biosphere acts as a net carbon sink (negative feedback) relative to the current situation. However, with increasing population, the demand for new agricultural land is large, and land cover changes with associated carbon emissions are likely completely to counteract the negative feedbacks described above.

Source: Vloedbeld and Leemans (1993)

main approaches to integration can be identified: the aggregate cost-benefit approach and the regionalized process-based approach.

The aggregate cost-benefit approach seeks to estimate the likely monetary costs and benefits of GHG-induced climate change in order to evaluate the possible policy options for mitigating or adapting to climate change. This is a macroeconomic modelling approach (see above), and has been applied to certain aspects of the greenhouse problem for many years. In particular, the methods have been used to compute the development paths for emissions of carbon dioxide and other greenhouse gases in the atmosphere (the driving force for climate change).

The approach commonly combines a set of economic models with a climate model and a damage assessment model. The economic models provide global projections (sometimes disaggregated into major regional groupings of countries) of likely future paths of supply and demand in commodities that can affect greenhouse gas emissions, on the basis of future world population and economic development. The models use price to determine the relative competitiveness of different technologies of energy production, while accounting for the long-term depletion of fossil fuels, allowing for the development of more efficient technologies and accommodating likely policies of emissions abatement. The time horizon considered can range from a few decades to several centuries.

Climate models refer to a suite of functions that are needed: first, to convert GHG emissions into atmospheric concentrations; second, to estimate radiative forcing of the climate; and third, to compute the climate sensitivity of the forcing (global mean temperature response to radiative forcing equivalent to a doubling of CO_2). They usually comprise simplified representations of the gas cycles, empirical methods of determining radiative forcing, and highly simplified equations for computing temperature response.

Damage assessment models are functions that provide an estimate of the likely impacts (costs) of climate change, usually as a percentage of GNP. They commonly provide a global estimate of 'damage' as a function of global mean temperature change. To date, such functions have been selected subjectively, on the basis of expert opinion or using the few quantitative estimates that are available of the possible sectoral impacts of climate change at the global scale. Great caution must be exercised, however, since simulation outcomes with these models can be very sensitive to assumptions, such as those concerning future discount rates and the estimated damage response. A further major difficulty is the assignment of value to intangible non-market 'goods' such as human well-being, a pollution-free environment, and biological diversity.

Recent examples of models exhibiting this type of three-component framework include DICE (Nordhaus, 1992); CETA (Peck and Teisberg, 1992); and MERGE (Manne *et al.*, 1993).

The regionalized process-based approach attempts to model the sequence of cause and effect processes originating from scenarios of future GHG emissions, through atmospheric GHG concentrations, radiative forcing, global temperature change, regional climate change, possible regional impacts of climate change and the feedbacks from impacts to each of the other components. Regional impacts can be aggregated, where appropriate, to give global impacts which can then be used in evaluating the likely effectiveness of global or regional policies. The approach is derived from the applied natural sciences, especially ecology, agriculture, forestry and hydrology, where climate impact assessment has evolved from site or local impact studies towards large area assessments, using process-based mathematical models in combination with geographical information system (GIS) technology. Examples include two related models: ESCAPE (European focus) and MAGICC (global) (Rotmans *et al.*, 1994; Hulme *et al.*, 1995a), and two versions of a global model: IMAGE 1.0 (Rotmans, 1990) and IMAGE 2.0 (Alcamo, 1994). Box 1 illustrates an application of IMAGE 2.0, probably the most advanced model of this kind yet to have been developed.

In contrast to the aggregate cost-benefit approach, the estimates of biophysical impacts in these models are quantitative and regionally explicit. In addition, the treatment of gas cycling and climate change are usually more sophisticated than in the former approach. The economic impacts of climate change are not yet incorporated, however, and future versions of these models will strengthen their regional economic and global trade components, thus offering a quantitative assessment of the 'damage' quantities described above. Some of these developments are discussed further in relation to IMAGE 2.0 (Alcamo, 1994), AIM (Asian-Pacific Integrated Model; Morita *et al.*, 1993) and GCAM (a model being developed for the United States and other industrialized countries; Edmonds *et al.*, 1993).

The two types of approach outlined above originate from quite different disciplinary perspectives and were developed for contrasting reasons. However, it is becoming increasingly evident that major refinements of one approach will require significant contributions from the other. Indeed, it appears that the two approaches are rapidly converging towards a common, interdisciplinary method that will become a standard tool in policy analysis. Nevertheless, there are numerous problems associated with integrated system models, including their complexity, lack of transparency and demanding data requirements for calibration and testing. Further, modellers should take care to balance the sensitivity and uncertainties of model components, so that the results do not merely reflect noise in the most sensitive components of a model. Moreover, a major concern remains about the ability of these models to represent the uncertainties propagating through each level of the modelled system. This is discussed further in Section 7.6.

4.3 Empirical Analogue Studies

Observations of the interactions of climate and society in a region can be of value in anticipating future impacts. The most common method employed involves the transfer of information from a different time or place to an area of interest to serve as an analogy. Four types of analogy can be identified: historical event analogies; historical trend analogies; regional analogies of present climate; and regional analogies of future climate. Analogues can also be used as climate scenarios (see Section 6.5.2)

4.3.1 Historical event analogies

Historical event analogies use information from the past as an analogue of possible future conditions. Data collection may be guided by anomalous climatic events in the past record (e.g., drought or hot spells) or by the impacts themselves (e.g., periods of severe soil erosion by wind). The assessment follows a 'longitudinal' method (Riebsame, 1988), whereby indicators are compared before, during and after the event. Examples of this approach are found in Glantz (1988). However, the success of this method depends on the analyst's ability to separate climatic and non-climatic explanations for given effects.

4.3.2 Historical trend analogies

There are several examples of historical trends that may be unrelated to greenhouse gases but which offer an analogy of GHG-induced climate change. Long-term temperature increases due to urbanization are one potential source for a warming analogue (as yet seldom considered by impact analysts). Another example is past land subsidence, the impacts of which have been used as an analogue of future sea level rise associated with global warming.

4.3.3 Regional analogies of present climate

These refer to regions having a similar present-day climate to the study region, where the impacts of climate on society are also judged likely to be similar. To justify these premises, the regions generally have to exhibit similarities in other environmental factors (e.g., soils and topography), in their level of development and in their respective economic systems. If these conditions are fulfilled, then it may be possible to conduct assessments that follow the 'case-control' method (Riebsame, 1988). Here, a target case is compared with a control case, the target area experiencing abnormal weather but the other normal conditions.

4.3.4 Regional analogies of future climate

Regional analogies of future climate work on the same principle as analogies for present-day climate, except that here the analyst attempts to identify regions having a climate today which is similar to that projected for the study region in the future. In this case, the analogue region cannot be expected to exhibit complete similarity to the present study region, because many features may themselves change as a result of climatic change (e.g., soils, land use, vegetation). These characteristics would provide indicators of how the landscape and human activities might change in the study region in the future. Of course, for a full assessment of this, it would be necessary to consider the ability of a system or population to adapt to change. This principle has proved valuable in extending the range of applicability of some impact models. For example, a model of grass growth in Iceland has been tested for species currently found in northern Britain, which is an analogue region for Iceland under a climate some 4°C warmer than present (Bergthorsson *et al.*, 1988).

Other aspects of the analogue region, however, would need to be assumed to be similar to the study region (e.g., daylength, topography, level of development and economic system). Where these conditions cannot be met (e.g., daylength for grass growth in Iceland differs from that in northern Britain), the implications need to be considered on a case by case basis. For a hydrological example, and discussion of the considerable problems involved with regional analogues, see Arnell *et al.* (1990). One method of circumventing these problems is to consider altitudinal differences in the same region.

4.4 Expert Judgement

A useful method of obtaining a rapid assessment of the state of knowledge concerning the effects of climate on given exposure units is to solicit the judgement and opinions of experts in the field. Of course, expert judgement plays an important role in each of the other analytical methods described above. On its own, however, the method is widely adopted by government departments for producing position papers on issues requiring policy responses. In circumstances where there may be insufficient time to undertake a full research study, literature is reviewed, comparable studies identified, and experience and judgement are used in applying all available information to the current problem.

The use of expert judgement can also be formalized into a quantitative assessment method, by classifying and then aggregating the responses of different experts to a range of questions requiring evaluation. This method was employed in the National Defense University's study of Climate Change to the Year 2000, which solicited probability judgements from experts about climatic change and its possible impacts (NDU, 1978, 1980).

The pitfalls of this type of analysis are examined in detail in the context of the NDU study by Stewart and Glantz (1985). They include problems of questionnaire design and delivery, selection of representative samples of experts, and the analysis of experts' responses.

More recently, decision support systems that combine dynamic simulation with expert judgement have emerged as promising tools for policy analysis. Here, subjective probability analysis is required where simulation empirical models are lacking. Participatory assessment is another approach which is being tested in the McKenzie Basin study in Canada (cf. Section 2.3.3)