Towards a general method for analysing regional impacts of global change

Thomas Malone and Gary Yohe

> I met three cats on my first day in Interlaken. To the first, I said 'Hello', but it ran off into the nearest bush. To the second, remembering that I was in Switzerland, I said *Guten Tag* and it marched right over to me for a minute of vigorous ear scratching. Encouraged by my success, I repeated *Guten Tag* to the third cat, only to be rebuffed by a haughty upward tilt of the head. I tried again, this time with a hesitant *Bonjour* and I was quickly rewarded by a quick and playful prance to my outstretched hand and several minutes of chasing leaves. When I wrote home to my family that night, I related the story in considerably more detail, and I wondered 'How do these Swiss cats communicate with one another?' How, indeed?

The need for full integration of social science perspectives, methods and personnel in analyses of global change impacts is a dominant theme of the Second World Climate Conference. The most troublesome effects of global change are likely to be felt at subnational levels but the integration of social and environmental science on these levels raises many challenging questions. One promising contribution to the methodology of regional analysis has been pioneered by a government-sponsored study of climate change in the central USA. This approach is capable of incorporating diverse inputs from a wide range of disciplines and professions and it is potentially applicable in developing countries as well as developed ones.

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In late October 1990, representatives from many countries gathered in Geneva at the Second World Climate Conference (SWCC) to assess the state of knowledge about climate and climate change, and to discuss a scientific strategy for responding to the anticipated changes. The essence of their deliberations is contained in the Conference Statement,[1] but its language falls short of a clear expression of the dominant conference theme, namely that it is time to integrate the social sciences more fully into analyses of global change impacts. For almost a decade, such impacts had already been monitored and analysed in the World Climate Impacts Program (WCIP), but participants in SWCC recognized a need to go further and involve social science researchers in every component of global change analysis.

It was recognized that both the effects of global change – and the effects of policies that are designed to slow its momentum – would be felt most strongly at local and regional levels, thereby giving rise to a need for improved understanding of the spatial spread of associated costs and benefits. A need to understand how various peoples and institutions might adapt to effects and policies was also recognized. In short, the time was judged to be ripe for accelerating the pace of interdisciplinary cooperation across the blurring boundary between natural and social science.

The clearest articulation of these views can be found in a call for the

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creation of regional research centres that was unanimously approved by the final plenary meeting of the SWCC:

> A specific initiative would create a network of regional, interdisciplinary research centers, primarily in developing countries, including all of the natural science, engineering, and social science disciplines required to support fully integrated analyses of global change and its impacts. Each center should give priority to bringing together individual investigators and decision makers from developed and developing countries. The centers would (1) conduct research on all aspects of global change, including policy options, (2) study the interaction of regional and global policies, and (3) educate and train scholars and decision makers.[2]

Even as the concept of regional centres was being approved, a long list of questions about them was being raised.[3] How would regional centres be coordinated? How would diverse regional analyses be made consistent with global scenarios of climate change? Could inputs and outputs to regional analyses both be made consistent with such scenarios? What common socioeconomic impact methodology might be applied in the regional centres to produce results that were, at least, comparable and, perhaps, capable of being integrated into a single detailed global portrait?

These questions, and others like them, will occupy the attention of many investigators over the coming years. But the process of engaging them was begun immediately after the closing session of SWCC when a small group of physical scientists and social scientists met in Interlaken, Switzerland, to foster a supporting interdisciplinary effort.[4] The importance of integrated regional analyses of global change effects was underscored six weeks later at a further meeting in Bellagio, Italy.[5] A specific proposal for regional centres was made by this meeting to the Scientific Committee of the International Geosphere–Biosphere Programme (IGBP). Less than two months later, the importance of regional activities was again emphasized by Howard Ferguson, Coordinator of SWCC, at a major international conference in Japan.[6] The push for integrated, regional analysis of global change impacts had begun to gather momentum.

This paper is designed to complement the steps that have already been taken by suggesting a possible set of rudimentary building blocks with which a widely applicable, regional impacts methodology might be constructed. The general methodology that is suggested here emerged mainly from the Interlaken workshop, but it is rooted in a climate change impact analysis that was conducted for the US Department of Energy by Resources for the Future. The latter study is widely known as the MINK project, because it pertains to the states of Missouri, Iowa, Nebraska and Kansas.[7]

The next part of this paper summarizes the MINK approach.[8] It is followed by a description of general principles that underlie the MINK study and an exploration of its applicability beyond the highly developed and highly integrated economic system of the USA. The means by which collaboration among natural scientists, social scientists, engineers, and policy analysts, among others, will be facilitated are then examined and the role of uncertainty is highlighted. The general method is seen as being capable of incorporating such complex considerations in a modular fashion that does not overwhelm the entire analysis. Finally, we turn to more philosophical concerns that were alluded to in the opening story about Swiss cats.

[1]Second World Climate Conference, *Conference Statement*, SWCC Secretariat, Geneva, 1991.
[2]These words were written by Task Group 12 (Synthesis) and brought forward for SWCC approval by the Panel on Special Needs of Developing Countries.
[3]See *op cit*, Ref 1, Part I, Section C, Paragraph 11.
[4]The Interlaken Workshop, sponsored by the US Department of Energy and the Tissot Foundation, was attended by 35 natural scientists and social scientists from 15 countries and 5 continents. The focus was entirely methodological and the MINK study provided a point of departure. See N.J. Rosenberg and P.R. Crosson, *A Methodology for Assessing Regional Economic Impacts of and Responses to Climate Change – the MINK Project*, Resources for the Future, Washington, DC, 1990.
[5]The Bellagio conference, 'Global Change Regional Research Centers: From Conception to Reality', was attended by 22 scientists from 12 countries. It laid the basis for creating a worldwide system of research networks designed explicitly for regional study. See J.A. Eddy, T.F. Malone, J.J. McCarthy and T. Rosswall, eds, *Global Change System for Analysis, Research and Training (START)*, International Geosphere Biosphere Programme Report No 15, Report of a meeting at Bellagio University Center for Atmospheric Research, Boulder, CO, 1990.
[6]H.L. Ferguson, 'Second World Climate Conference: Proposals for regional follow-up activities', in *Proceedings, International Conference on Climate Impacts on the Environment and Society*, University of Tsukuba, Tsukuba, Japan, January 1991.
[7]See *op cit*, Ref 4.
[8]See also N.J. Rosenberg *et al*, *Processes for Identifying Regional Influences of and Responses to Increasing Atmospheric Carbon Dioxide and Climate Change – The MINK Project*, Working Paper Series I-VI, Resources for the Future, Washington, DC, 1990.

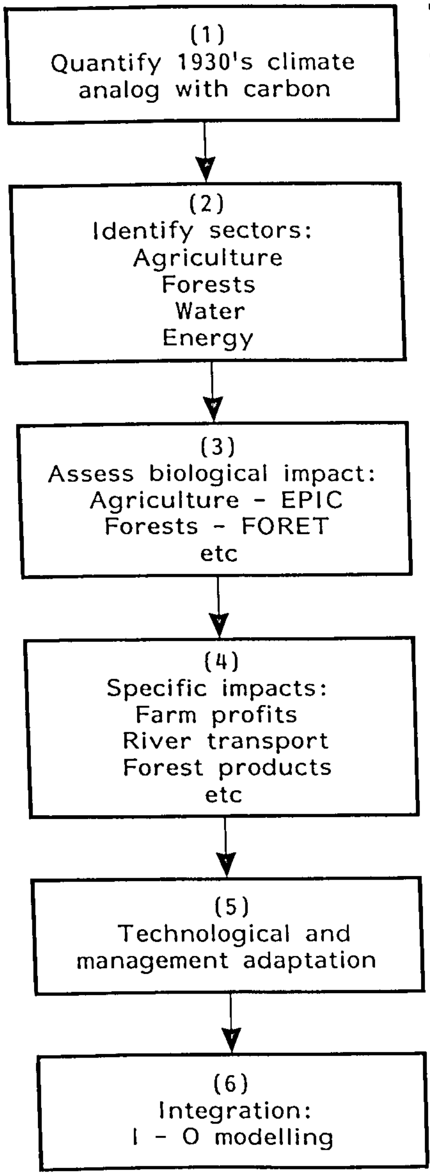

Figure 1. Steps in the MINK methodology.

The MINK methodology

The MINK study's designers prefaced their work with the observation that most previous assessments of climate change impacts suffered from a common set of methodological shortcomings. First, many were based on predictions of *annual* changes in mean temperatures and precipitation, whereas changes in seasonal, monthly, weekly, and daily climate variability were also likely to occur. Second, many complicated feedbacks have not yet been explored or incorporated into impact modelling. These include effects of carbon dioxide fertilization and carbon induced changes in evapotranspiration. Third, systematic consideration of local, regional and national adaptations to climate change were not taken into account.

The methodology that was developed to overcome these limitations included the following components:

- A baseline description of the resources of the MINK region and its existing economy.
- An analog historical climate of the region, and a range of existing adaptive technological alternatives.
- A baseline description of how the region might function after 20 years and 40 years of likely technological changes.
- An application of the historical climate to the region described by the new (20 and 40 year) baselines.

For each of these components, three orders of effects were assessed:

- First-order effects that influence resource productivity directly.
- Second-order effects which incorporate the responses of primary enterprises such as farms and water districts to first-order effects.
- Third-order effects which reflect regional economic responses beyond immediately impacted sectors.

The results provided information about the effects of altered climate on the MINK region and took account of spatial and temporal variability.

Figure 1 shows how all the previously described tasks were tied together. It begins with the selection of the Dust Bowl climate of the 1930s as the historical analog climate for the MINK study (Step 1). That decade brought higher temperatures and lower precipitation to the MINK region. Since daily weather data were available for many locations within the region, much spatial and seasonal variability was captured. Increased atmospheric carbon dioxide concentrations (to 440 ppm) were also included.

The second and third steps identified four major economic sectors of the region that might be vulnerable to altered climate and assessed their vulnerability. Agriculture, forests, water and energy were selected (Step 2) for analysis. Texas A&M University's EPIC (Erosion Productivity Impact Calculator) model was modified in Step 3 to handle both spatial variations in soil types, rotation, tillage and irrigation, and also the effects of carbon fertilization and evapotranspiration. Other models were also employed. For example, the FORET model was adapted to portray forest vulnerability. All the modelling employed in Steps 2 and 3 exploited the rich spatial and temporal variability that was provided by 1930s weather data.

Step 4 translated the physical effects identified in Step 3 into social and economic consequences without adaptation. The post-adaptation situation was derived in Step 5. Economic data and modelling results

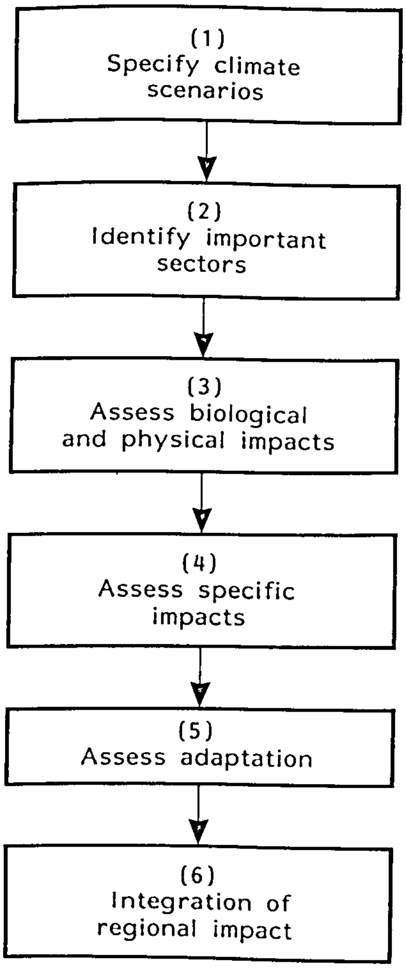

Figure 2. Application of the MINK project framework in a less data-rich setting.

were critically important in both stages. They simultaneously provided a metric for gauging the severity of climate change effects and for triggering various adaptation strategies that would, or should, be undertaken by individuals and private enterprises as well as public institutions. A final economic integration was accomplished in Step 6 by means of input–output modelling in the MINK study. This provided an aggregate portrait which is both a final product of the analysis and a potential input to a larger national, international or global analysis.

A more general methodological description[9]

The specific modelling exercises and sensitivity analyses that were used in the MINK study made use of large quantities of data. Indeed the exercises and analyses were chosen, in part, because requisite data were available that permitted exploration of a wide range of physical, biological and economic processes.

It might be thought that such a data-intensive approach would frustrate efforts to apply this methodology to developing countries where data are sparse and intricate models are rare. But the underlying framework of the MINK project is also capable of being applied in less data-rich settings. Figure 2 illustrates this point. Once again a series of tasks begins with:

(1) Selection of a scenario that includes climate-altering atmospheric emissions, concentrations and physical impacts.

This time these variables are regional in nature, but linked with similar scenarios for other regions in a globally consistent pattern in the following sequence:

(2) Identification of important regional sectors.
(3) Assessment of biophysical impacts on sectors.
(4) Assessment of resulting changes in important variables.
(5) Identification of individual and institutional responses.
(6) Integration of responses across regions.

The message of Figure 2 is clear. Entries recorded in the various boxes of Figure 1 are, quite simply, the MINK Study Team's responses to the tasks that are described in corresponding boxes in Figure 2. If sophisticated data are not available, simpler data may be substituted. For example, there is no reason to employ EPIC if the necessary biological, geological or meteorological data are not available. A simpler alternative set of data will suffice. Likewise, FORET probably does not apply to unmanaged forests and so an alternative model would be substituted. In the end, it is the modular nature of the overall framework depicted in Figure 2 that allows it to function as a general method of organizing regional research efforts: every step can be completed with whatever tools and data happen to be available.

The validity of this assertion was confirmed in discussions with participants of the Interlaken Workshop from developing countries. For example, it was believed that the methodology could usefully portray African agriculture because sufficient data and associated crop models are available. Commercial forestry could be handled, as well, but social forests would be difficult to incorporate. The effects of rapid urbanization would be difficult, but not impossible, to integrate in a water-use module.[10] Similar impressions were advanced by participants from the People's Republic of China and Brazil.[11] Most participants offered

[9]This section is based largely on comments offered by participants at the Interlaken Workshop. Specific contributions are acknowledged.
[10]Personal correspondence with Dr Christopher Magadza, University of Zimbabwe.
[11]Personal correspondence from Dr Kuo Jobin (State Meteorological Administration, Beijing), Dr Zhang Jiachen (State Meteorological Administration, Beijing), and Dr Antonio Magelhaes (Brazil).

words of encouragement, but all counselled caution when considering individual and institutional contexts of adaptation.

This latter condition particularly affects Boxes 4 and 5 of Figure 2. For example, decentralized market mechanisms do not apply universally. African agriculture is frequently organized communally, with the national government serving as a marketing agency. An African agricultural economy is likely to be more loosely integrated than the US one that was evaluated in the MINK project. Moreover, agriculture is often an overwhelmingly important sector of the economy in developing countries, subject to strong influences from the international flow of exports and imports. Taken together with the transboundary flow of international rivers and other water resources, this observation underscores the importance of ensuring that regional climate change impact scenarios are globally consistent.

The MINK project had a strong economic focus but the underlying conceptual framework involves principles and issues that extend well beyond the traditional boundaries of economics into other social sciences. Nonetheless, the general method is applicable if the following conditions are met:

- The special institutional structures of a region are captured in the integration procedure of Box 6.
- The motives behind the behaviour of the region are reflected in the adaptive responses included in Box 5.
- At a minimum, the qualitative nature of important units is represented in Boxes 3 and 4.
- The evolving structure of the region is captured in the linkage between Boxes 1 and 2.
- Appropriate boundary conditions that are likely to link the region with the rest of the world are clearly and consistently defined.

Taken separately or together, the complexity of the tasks that are inherent in this methodology make clear that its application will require true interdisciplinary research.

Integration across disciplines

The previous section closed with a recognition that many important social science issues can be buried beneath the symbolic shorthand of Figure 2. The Standing Committee on the Human Dimensions of Global Change of the International Social Science Council (ISSC) recently published a research framework that highlights broad requirements for an integrated programme of global change research.[12] Seven specific programmes of inquiry were identified. Every one requires the full participation of a wide range of social scientific specialities:

(A) Social dimensions of resource use.
(B) Perception and assessment of global environmental conditions and change.
(C) Impacts of local, national, and international social, economic, and political structures and institutions.
(D) Land use.
(E) Energy production and consumption.
(F) Industrial growth.
(G) Environmental security and sustainable development.

[12]H.K. Jacobson and M.F. Price, *A Framework for Research on the Human Dimensions of Global Environmental Change*, International Social Sciences Council, Barcelona, 1990.

There is, however, more to this framework than the consolidation of social science research. The Committee echoes the SWCC call for true collaboration between social scientists and natural scientists who are working on global change. The report of Task Group 12 to SWCC noted, quite explicitly, that there is an acute need for *integration* within the scientific effort:

- Across the domains of the climate system (eg ocean, land, atmosphere, etc).
- Among the relevant disciplines (eg physical sciences, biological sciences, economics, policy analysis, other social sciences, engineering, etc).
- Between *positive* (norm-free) scientific studies and impact analyses and *normative* decision making processes.
- Between climate change and other environmental concerns.
- Between developed and developing countries.

It is the intent of both the Task Force's statement and the Work Plan of the ISSC that any research method must meet these needs directly and immediately.

Figure 3 underscores both of these thrusts by highlighting the linkage of social and physical effects within the general structure of Figure 2. The methodology begins with the definition of a natural process – under prevailing conditions of economic growth and distribution – but quickly moves into the interaction of important societal sectors with their physical environments; environments that are best characterized by natural scientists. The sectors chosen for analysis are important not only because of their salience, but because they are potentially vulnerable to physical system changes. The method proceeds to consider possible adaptation and integrates across sectors to generate a holistic regional portrait. These steps rely on thorough understanding of human and institutional behaviour – the bailiwick of social science – as well as visions of technological possibilities – the province of engineering.

All these interdisciplinary linkages are exemplified in the MINK study. In that study, the agricultural module began with the interaction of crop modellers and natural scientists around the task of incorporating carbon dioxide fertilization into yields forecasts; but they both also worked with economists to compute associated patterns of profitability. Knowledge of expert systems and individual risk behaviour were also employed when various adaptation strategies were investigated. Even the input–output economic integration of the region reflected socioeconomic content, namely the strong reliance of MINK on market structures. But the success of the MINK project was directly related to the ability of natural scientists and social scientists to interact, to recognize their different needs, and to understand the limitations of each group's knowledge.

Figure 4 sets the research method of Figure 2 in an even broader context by indicating where the seven ISSC research tasks might come into play. They all appear at least twice – once as forcing determinants of global change and again as indicator effects of potential adaptations. This dual role was noted in the text of the ISSC Research Framework, but the language used to describe the tasks clearly shows that initial research will concentrate on forcing factors.

Figure 4 also explicitly records the location of policy effects, and thus the arenas for policy analysis. There is, once again, a dual forcing-

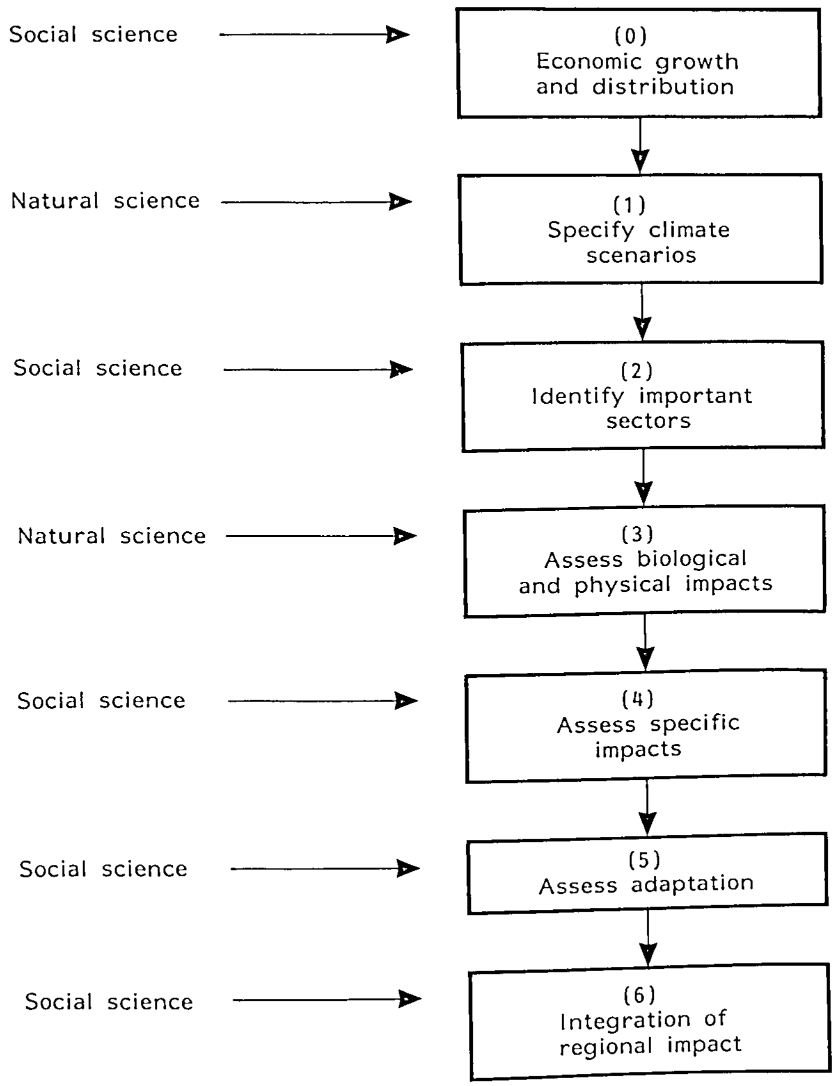

Figure 3. Linkage of social and physical effects within the general structure of Figure 2.

effects pairing of roles, but several additional points should be emphasized. Mitigation policies are highlighted on the effects side, and the reason for their inclusion is obvious. Much of the policy debate conducted thus far has focused on regulation, restriction, and/or taxation of emissions of greenhouse gases. These are policies designed to limit the rate of growth of atmospheric concentrations of radiatively active gases and thus to slow or eliminate the rate of climatic change. The effectiveness and design of these policies – and the likelihood of their successful implementation – should be captured on the forcing side, both directly and indirectly through their effect on economic growth.

Mitigation policies do not stand alone on the forcing side of Figure 4. Other policies can affect the rate of global change even though they are not directly linked. Non-environmental policies, such as economic stabilization programmes that affect the rate or consistency of economic growth and investment, can have important effects on the emission of greenhouse gases. Faster, more consistent growth can accelerate emissions, while increased investment in new, cleaner technology can slow

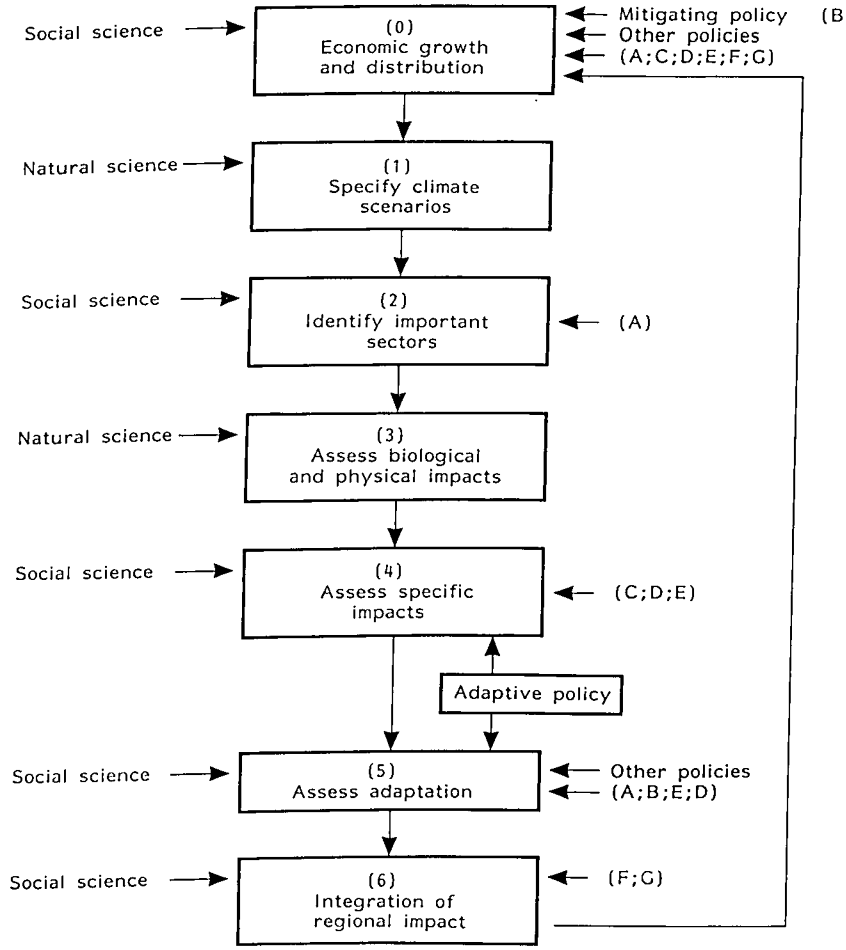

Figure 4. The application of the ISCC research tasks to the research method shown in Figure 2.

The research tasks A,B, etc are identified in this paper at the beginning of the section 'Integration across disciplines'.

them down. Similarly, environmental policies designed to limit emission of specific pollutants with radiative properties can have direct effects. More restrictive or more effective policies that, for example, reduce sulphur emissions can certainly slow greenhouse warming, but only if they do not encourage the emission of other more absorptive chemicals.

Other policies also appear on the effects side of Figure 4 for similar reasons. They can have dampening or complementary effects. For example, preferential financial arrangements for the general modernization of social infrastructure might, incidentally, promote investment in capital that makes a region more or less vulnerable to changing climate and thereby alters the need for adaptive responses. Policies designed to share economic risks might slow the rate of adaptation by making individuals and institutions less sensitive to changes in physical and/or economic environments.

Finally, Figure 4 displays a large feedback loop from regional impact after adaptation and global change forcing. There are, here as well, direct and indirect effects that need to be considered. Some adaptation might slow economic growth, and indirectly slow the rate of global change. Adaptation might also alter emissions directly as people behave differently, without the need for elaborate institutional arrangements. Every one of the policy arenas that have been identified needs to be considered in turn. Figure 4 suggests, at the very least, a way of organizing the results of such considerations.

Uncertainty

The SWCC recognized that uncertainty '. . . alone must not be the basis for deferring societal response' to risks imposed by the impacts of potential global change.[13] It was understood that most readers would interpret this statement to support the immediate imposition of global mitigation strategies. But there is more to it than that. Coping with climate change will occupy much of society's attention over the coming decades, and responses to its consequences will be required before the uncertainties are resolved. This is so whether the uncertainties are global emissions reduction policies that fit into the top of Figure 4, regional adaptive policies that fit into the bottom of Figure 4, or individual cost-reduction behaviours that fit into the core of Figure 4.

Fundamental uncertainties pervade regional analysis, and every step in Figure 4 has its own set. Their role is particularly significant in Boxes 2 and 5. As noted earlier, identification of the most important sectors in any region (Box 2) emerges from a process which weighs the size of candidate sectors against their vulnerability to climate change. Vulnerability is, in turn, defined by a wide array of variables whose future trajectories are unknown. It is essential that a ranking of the sensitivity of major sectors to these underlying variables be made available to investigators who are describing climate scenarios (Box 1).[14] Only then will they know how to characterize future climate in the most generally useful terms. It follows, of course, that the set of important descriptive variables might not be the same for all regions. This underscores the necessity of expressing globally consistent climate scenarios for different regions in terms of different parameters.

Adaptive decisions (Box 5) must also be cast in terms of the quality of information that will be available when they are likely to be considered. To the extent that many of the uncertainties which cloud our view of the future are fundamental, even future decisions will not be made with perfect information. They will, nonetheless, be informed by the experience gained during the intervening timespan, so consideration of what might be decided – and when – should include some recognition of what might be learned as the future unfolds in accordance with the climate scenarios defined in Box 1.

Yohe suggests a means of taking future knowledge acquisition into account in the policy arena.[15] The method explicitly incorporates a Bayesian learning technique to inform future policy makers. It also supports investigation of the value of new information that may become available in the future, derived either from an endogeneous learning process or from an exogeneous research effort. The result provides (a) a ranking of alternative response strategies (including their best timing); (b) a current ranking of response strategies and timing expectations in light of what might be learned in coming years; and (c) a catalogue of the exogeneous information that might be most useful.

Adaptation under conditions of uncertainty need not be confined to policy decisions, but the thought process which ponders the timing and structure of future policy can also be applied to less official responses. It is easy, for example, to conceive of real-estate markets depreciating the value of property that is threatened uncertainly by some manifestation of changing climate. As the risk becomes more certain and the date of impact draws closer, the rate of depreciation would accelerate. Compared to a circumstance without foresight, this market response – signalled only by the behaviour of informed participants – would

[13] Second World Climate Conference, *Conference Statement*, SWCC, Secretariat, Geneva, 1991, Executive Summary, Paragraph 2.
[14] A.M. Liebetrau and M.J. Scott, 'Strategy for modelling uncertain impacts of climate change', *Journal of Policy Modelling*, Vol 13, No 2, 1991, pp 185–204.
[15] G.W. Yohe, 'Uncertainty, global climate and the economic value of information', *Policy Sciences*, Vol 24, No 3, 1991, p 245–269.

automatically redirect investment out of harm's way and thereby reduce the opportunity costs of not stopping the damaging climate impact. Incorporating anticipated adaptations of this sort, weighted again by the present subjective view of likely regional ramifications of various global change scenarios, should be critical in assessing the benefits of enacting a previous mitigation response.

Individual decisions can also play a significant role in reducing the potential costs of changing climate. This has been considered in the context of decisions by risk-averse farmers to switch crops as they experience annual episodes of new weather that accompany a changed climate.[16] Maximum damage should be expected if farmers do not respond, but it is reasonable to expect some reaction to changing conditions based on recognition of mean annual profitability per unit of land and annual variability around that mean. Modelling suggests that crop switching can be anticipated well before farmers become absolutely convinced that climate has changed, and that the time series of losses which they would experience would be less severe if they were equipped with accurate and timely *climate* information. Generalization of these insights underscores the importance of including individual responses among the list of automatic adaptations which must be anticipated in regional analysis of climate change.

Conclusion

The Interlaken Workshop began with a plenary session address by Professor James Dooge, Chair of SWCC, who encouraged the participants to engage in 'good conversation' – to talk clearly, to listen carefully, to focus intently, and to work to develop a common language of communication. It is good advice for all. Taking it to heart we found that the MINK methodology provided a rich arena within which to make progress in furthering understanding of potential climate change impacts and in furthering communication across disciplinary and geographical boundaries.

The underlying significance of the advice offered by Professor Dooge was, of course, never lost on the cats of Interlaken. When they deal with their people, they listen and respond to French, German and English perhaps, and to a wide variety of other languages which are spoken across Switzerland. But when they deal among themselves they speak a common feline language of mutual respect and concern, especially when they confront the large dog down the street or the occasional cow which has escaped from the fenced pasture of the central commons. The global community is facing an enormously threatening 'dog' in the form of global change, and we desperately need to find that elusive common language of respect and concern that will allow natural scientists, engineers, social scientists, decision makers, and individuals from developed countries and developing countries alike to communicate and work together. Beyond the specifics of a methodology which can support integrated regional analyses across the globe, therefore, the generalized structure of the MINK study is advanced here as a contextual framework within which an integrated language of concern for our common environment might evolve. It is not a language that will emerge from *thinking* about how to attack the problem. It is a language that will evolve only when we *engage* the full range of relevant disciplines in the attack itself. We must stop talking about it and start doing it, region by region.

[16] G.W. Yohe, 'Embedding dynamic responses with imperfect information into static portraits of the regional impact of climate change', in *Global Change: Economic Issues in Agriculture, Forestry and Natural Resources*, US Department of Agriculture, Washington, DC, 1991.