International policy perspectives on global atmospheric change: Expanding the range of options

International policy perspectives on global atmospheric change: Expanding the range of options

Testimony for the

Hearing on Greenhouse Effect and Global Change
Committee on Commerce, Science,
and Transportation
United States Senate

February 22, 1989

by

William C. Clark
John F. Kennedy School of Government
Harvard University
79 Kennedy Street
Cambridge, MA 02138
United States of America

International policy perspectives on global atmospheric change: Expanding the range of options

William C. Clark

1. The global context of atmospheric change

Questions raised by the changing character of the world atmosphere have been intensely studied over the last decade. Several recent reports, most notably those of the US Global Change program and International Geosphere- Biosphere Program, have summarized the scientific findings of this work[1]. The question remains, So what? What are the practical implications for policy?

The following pages seek to sketch a useful framework for reflecting on how answers to the "So what?" question might look, and on how we might go about getting them. It does not attempt to provide the answers themselves, nor to summarize the answers that others have given.

Some justification for this approach is warranted. Policy makers and people in general have become increasingly impatient with a scientific community that always seems willing to raise possibilities of terrifying things that might go wrong, but never seems willing to commit itself on how seriously the possibilities should be taken, or on what action they require. Why shouldn't we finally attempt a "bottom line" assessment of the policy implications of the global atmospheric change? Can general frameworks of the sort proposed here really provide a more useful approach?

My own response to this challenge is based on four fundamental characteristics that stand out in recent reviews of global atmospheric change[2]:

* Possible causes and effects of atmospheric change are intimately linked to other problems of energy, agriculture, population and environment. The linkages are physical, biological, economic and political. Action taken on problems like stratospheric ozone depletion will reshape the greenhouse question; actions taken on the greenhouse problem will affect other atmospheric issues in turn. The policy implications of global atmospheric change cannot usefully be addressed without accounting for linkages among related problems and their solutions.

* The problems of atmospheric change are simultaneously local and global. For example, all countries of the earth are potentially affected by environmental changes related to the greenhouse effect; no country can do much unilaterally to forestall those changes. The nature, severity and perception

of greenhouse-related impacts will nonetheless differ greatly among peoples and places. A useful discussion of the policy implications of atmospheric change must reflect these differing local and national perceptions of an intrinsically global phenomenon.

* Finally, uncertainty dominates every aspect of global atmospheric change, from emission rates through environmental consequences to socioeconomic impacts themselves. Assessments that do not address these fundamental uncertainties will be extremely misleading. Useful policy analyses must find ways of characterizing the implications of our incomplete scientific knowledge. They must highlight the impossible and barely possible as well as the most probable impacts of the increasing impacts of human activities on the atmosphere.

"The" problem of global atmospheric change thus has much in common with other grand concerns like "the" population problem or "the" problem of economic development. Such multifaceted, complex problems can be better described as "messes". Experience with messes suggests that any attempt to resolve them will be futile if it presumes the existence of a few key "decisions" or "decision makers"[3]. Like the population and development messes, atmospheric change will have different practical implications for different sectors of the economy, different nations, and different generations. Each of these will make its own interpretation of costs, benefits, uncertainties and suitable responses. Most of whatever social responses do occur will consist of each group's incremental adjustments to its own ongoing activities, taken in the context of its own agenda of other problems and solutions. In such a real world mess of multiple actors and actions, no-one's needs will be served by single "bottom line" assessments that purport to speak for all people and all times.

More useful would be a set of effective tools and approaches that individual nations and interest groups could employ in coping with the practical implications that global atmospheric change may hold for them[4]. Collaborative use of the tools to shape regional or even global responses would be possible, but independent local responses would be facilitated as well. The tools most needed would help to shape incomplete scientific understanding so that it can be critically applied in the construction of appropriate social responses. They would be useful for expanding the conventional menu of possible social responses and for characterizing their respective strengths and limitations. They would provide means of addressing, if not resolving, each of the fundamental characteristics of global atmospheric change listed above. Ideally, the tools could also be used to fashion a commonly accepted, relatively unbiased perspective from which the different interests in the debate over global atmospheric change would better comprehend each others' concerns and preferred actions.

Several recent studies have begun to construct important components of the set of tool needed for coping with practical implications of global atmospheric change. Despite some gratifying progress, however, the tool kit needed for societies to cope effectively with global environmental change is far from complete. For example, even the best policy analyses and assessments have tended to take their questions from the immediate concerns of natural scientists studying global atmospheric change, and to concentrate on providing answers. But as Thomas Schelling has shown in the most perceptive treatment yet written on social implications of global atmospheric change, this approach leaves many of the most practically relevant questions unformulated and unstudied[5]. Missing are the broader perspectives that could help to locate questions of atmospheric change within the context of related economic trends, political agendas, and environmental problems. It is these contextual issues that will both shape impacts of atmospheric changes on societies, and provide societies with their options for dealing with those impacts. The remainder of this paper attempts to characterize some of the missing perspectives and to provide some of the tools needed for working with them.

2. Linkages in global atmospheric change

As noted above, changes in the global atmosphere are tightly coupled to one another, not only through their physics and chemistry, but also through their common human sources and impacts. A synoptic perspective that emphasizes these linkages is necessary for the development of effective and efficient policies.

One step towards this such a synoptic framework has been developed by Drs. Paul Crutzen of the Max-Planck Institute for Chemistry, and Thomas Graedel of ATT-Bell Laboratories[6]. The approach adopted by Crutzen and Graedel can usefully be viewed as a form of environmental impact assessment[7]. Experience in environmental impact assessment shows the importance of beginning with an explicit statement of valued environmental components, ie. properties of the environment that are thought to be most worthy of attention or protection in a given assessment context[8]. As such, valued environmental components (should) reflect the judgments of the broader political and social communities as well as those of scientific experts. For illustrative purposes here, the valued environmental components identified by Crutzen and Graedel and described in Table 1 will suffice.

Environmental impact assessment aims to establish the causal relationships between valued environmental components and potential sources of environmental disturbance. The last decade has brought about major advances in our understanding of the atmosphere, its chemistry and physics, and its interactions with the biosphere[9]. Figure 1 shows the results of Crutzen and Graedel's initial effort to summarize our present knowledge of the relative influence of various sources of change on valued components of the atmosphere.

Each cell entry of Figure 1 indicates the relative impact of the specified perturbation source on the specified valued atmospheric component. This can be seen more clearly in terms of the specific example of the impact of coal combustion on the thermal radiation budget (Location 'a' in Figure 1). Obviously, the details of such an assessment can be enormously complicated. Large research programs, scientific monographs, and official reports have focussed on just one or two cells of the matrix (eg. the many works on "energy and climate")[10]. Even these relatively narrow efforts inevitably end up pushing scientific understanding to and beyond its limits. For this reason, some estimate of the relative confidence that the scientific community has in its inevitably incomplete and uncertain assessment is essential. Crutzen and Graedel have therefore included a qualitative expression of relative uncertainty in each of the cell estimates given in Figure 1.

Column assessments: The most useful aspects of the framework developed by Crutzen and Graedel are not their individual cell assessments, but rather the synoptic perspective gained by viewing the relations among those cells. Two dimensions of this synoptic perspective merit special attention. First, consider the "cumulative impact assessment" that comes from looking down any individual column of Figure 1 and noting all of the natural fluctuations and human activities that significantly affect a specific valued atmospheric component. In the case of the thermal radiation budget, the figure summarizes our understanding that while fossil fuel combustion is now the dominant source of anthropogenic climate change, other factors including certain industrial processes, biomass burning, crop production, and changes in the biological activity of natural vegetation and soils all may play a significant role. As several recent reports have emphasized, efforts to understand the likely course and implications of climate change must move beyond a preoccupation with individual chemicals like carbon dioxide, to include a comprehensive appreciation of the multiple sources involved.

Row assessments: The second synoptic dimension of environmental perspective summarized in Figure 1 comes from looking across individual rows. This view shows all of the valued atmospheric components significantly affected by a specific source of natural fluctuations or human perturbation. It is the aspect of the Crutzen and Graedel framework most immediately responsive to the "action" orientation of policy making. The figure shows that policy measures taken to change the source of perturbation to one valued environmental component will almost inevitably affect other environmental components as well. To continue our earlier example, action to reduce coal combustion because of its impact on climate (Location 'a' in Figure 1) could also be expected to have a significant effect on photochemical oxidants, the acidity of precipitation, visibility, materials corrosion, and probably the absorption of ultraviolet radiation. The extent of the effect would obviously depend on the details of the policy adopted. But one conclusion is inescapable: if we are going to produce useful knowledge for guiding policy choices, a much greater portion of our assessment resources and attention must be put into row assessments of the net impact of major policy options across a wide range of valued environmental components. This is a difficult but not impossible task. A few studies have attempted partial "row assessments", among them the US National Academy of Science's reports on Nuclear and Alternative Energy Systems and on Atmosphere- Biosphere Interactions[11]. The pitfalls and potential revealed through such studies provides a foundation of experience on which the present generation of policy analyses of global atmospheric change can be built.

3. Enriching the range of policy options

The range of possible policy responses that has been explored in the debate over global atmospheric change remains extremely narrow. Most discussions reflect a preoccupation with actions that would reduce the production of pollutants like CO_2 or SO_x through changes in energy policy. Much less attention has been paid to the possibilities for adaptation to changing agricultural conditions, sea level, or other impacts of change in valued atmospheric components. Managerial options to restore damaged systems have been virtually ignored. In other contexts, expanding the range of actively debated options for action has often been one of the most useful roles played by policy analysts[12]. Needed are tools that can systematically survey possible leverage points across the whole sequence of interactions running from human actions through environmental change to social consequences.

A point of departure for constructing such tools is the classic model for environmental impact assessment shown in the upper panel of Figure 2. In this useful caricature of complex reality, human activities like fossil fuel combustion release pollutants and other substances like carbon dioxide. These substances interact with a variety of other environmental constituents and processes. Changes result in one or more valued environmental components like climate. These changes in turn have social consequences through their impacts on important properties like agricultural yield.

As noted above, most thinking on possible policy interventions to this sequence has focussed on its two extremes, ie. on polluting activities and on social consequences. Thomas Schelling, however, has argued that policy responses are in general possible at each stage of the sequence[13]. To help guide the design and assessment of specific policy options, he posed a framework consisting of four potential goals for social response, one corresponding to each stage of the classic assessment model. In a form slightly altered to give greater generality, these potential goals are listed in the bottom panel of Figure 2.

Altering production of pollutants changes the possibility of inducing environmental changes in the first place. Such changes might, of course, be beneficial. The framework makes no presumption that less production is better than more. Figure 1 makes clear, however, that changes to reduce the production of emissions from fossil fuels would have beneficial impacts across a wide range of environmental components. Recovering releases of emissions from the environment is another potential solution. It has seen extensive use in combatting problems of acidification, but little as a component of policy responses to the greenhouse problem. Social responses capable of modifying the environment could counteract unwanted changes in valued environmental components, or encourage wanted ones. A long tradition of environmental management, impact mitigation and ecosystem restoration activities reflects efforts to achieve this goal. New efforts in intentional climate modification, long range water transport or reforestation may be called for by emerging global problems. Finally, the goal of adapting to change can be pursued through a wide range of formal policies and informal actions that seek to mitigate the damages and capitalize on the opportunities associated with changing environments.

Space does not permit the detailed consideration here of specific policy options for addressing each of these goals for the management of global atmospheric change. Some of the more obvious possibilities are summarized in Table 2[14]. More generally, however, the national and international policy efforts should be encouraged to undertake systematic and imaginative explorations of the full options framework suggested here.

4. Policy Exercises: Learning to cope with global atmospheric change

This note has focussed on the design of tools that, I have argued, individual nations and interest groups should find useful in coping with the policy implications of global atmospheric change. Clearly, many of the proposed tools have barely been sketched. None are as well developed as they might be. All would benefit from further efforts directed towards their improvement. But with all tools and would-be practical devices, there is a limit to how much improvement can be expected from theoretical studies divorced from actual conditions of use. And no tool has value independent of the skills of its user -- skills that can only be learned through long and continuing practice. If the tools and approaches suggested here are to evolve into something of practical value for societies, societies must find ways of putting them to work. Only such exercises in application can produce a realistic feel of how we can best use the tools, of what are their actual strengths and limitations, and of where they can best be improved[15].

What might such exercises look like? What skills would they try to develop? How would they provide opportunities to apply and test our incomplete understanding of global atmospheric change and possible policy responses to it?

The need for practice: Practicing with Earth itself obviously has its drawbacks. Scientists may speak of the human releases of carbon dioxide to the atmosphere as "a great geophysical experiment", but the results of this particular experiment may come in a bit late to be of much use for those living in the test tube. The obvious alternative of practicing on various mathematical models of the Earth also leaves much to be desired. Any notion of confidently predicting the practical consequences of alternative response options wilts under the numbing scale and complexity of global atmospheric change, the profound uncertainties that remain in our scientific understanding of it, and its dependence on equally complex and uncertain "background" changes in the world's environments and societies. Moreover, even in simpler contexts, formal models have generally not been conducive to the close interaction among scientists, politicians, and other people that would be such an important aspect of social learning to cope with the global atmospheric change.

More useful means of practicing how to cope with complex interactions of environments and societies are badly needed. Considerable attention has been devoted to these needs in the program on "Sustainable Development of the Biosphere" now being carried out by IIASA, the International Institute for Applied Systems Analysis's[16]. Following an extensive review and evaluation of experience with alternative approaches[17], the IIASA effort has developed a program of "policy exercises": organized efforts that bring together policy people, scientists, and technologists to practice writing "future histories" of plausible interactions between societies' development activities and the global environment. The possible relevance of these exercises to the design of policy responses for dealing with global environmental change is discussed below.

Political exercises and war gaming: Policy exercises are derived from approaches developed in support of political- military strategic planning during the late 1950's and early 1960's[18]. At that time, experience had shown that formal models were inadequate to capture the contingencies, the unquantifiable factors, and the contextual richness that seemed central to the main lines of political evolution between the great powers in the period 1955- 1965. The models also tended to strengthen rather than relax the barrier between analysts and practitioners of political and military strategy. In attempting to design more useful integrative approaches, Herbert Goldhamer of the Rand Corporation realized that his "problem was similar to that confronting historians. He was faced with the task of writing a 'future history' to clarify his ideas about the motives and influences affecting the behavior of great powers, their leaders, and others in the real political world."[19]

The method devised by Goldhamer and his colleagues to write these future histories was dubbed "political gaming". Teams of human (as opposed to computer) participants were confronted with generally realistic problem scenarios and required to work through responses both to the scenario and to the moves made by other teams. The role of "Nature", which determines the impact on conditions of play resulting from the moves of the teams, the injection of unexpected events, the introduction of constraints on allowable responses, and so on, was played by the control team responsible for organizing the exercise.

Brewer has described four "difficult questions that eluded or exceed the capacity of alternative analytic tools" that were explored by the original political exercises[20]. These questions sufficiently resemble those that confront us in learning to cope with global atmospheric change to warrant quoting here:

* What political options could be imagined in light of the conflict situations portrayed? What likely consequences would each have?

* Could political inventiveness be fostered by having those actually responsible assume their roles in a controlled, gamed environment? Would the quality of political ideas stimulated be as good or better than those obtained conventionally?

* Could the game identify particularly important, but poorly understood, topics or questions for further study and resolution? What discoveries flow from this type of analysis that do not from others?

* Could the game sensitize responsible officials to make potential decisions more realistic, especially with respect to likely political and policy consequences?

Future histories of global atmospheric change: Experience with political gaming indicated that each of the preceding questions could be given an answer of "yes, but only under favorable conditions"[21]. The same experience led to several additional conclusions suggesting that the political exercises might serve as a basis for designing policy exercises to practice social responses to the problems of global environmental change. Elsewhere, I have dealt at some length with these potential linkages between exercises in political and environmental policy[22]. Some of the most important are summarized below:

* The political games were found to perform better than alternative approaches in studying "poorly understood dynamic processes... [and] institutional interactions" and in "opening participation to many with different perspectives and special competencies, on a continuing basis over time".[23]

* "The selection of competent professionals to participate in the political exercise proved to be critically important. This situation is analogous to that in chess or other games when inferior players tend to consolidate their own bad habits rather than being stimulated to improved or inspired play"[24]. To be useful, policy exercises on the problems of global environmental change would almost certainly have to involve several of the very top scientists who have been involved in recent assessment efforts, plus their opposite numbers from the world of politics, finance, and industry.

* "[O]ne of the most useful aspects of the political game was its provision of an orderly framework within which a great deal of written analysis and discussion took place... [O]ral or written discussion of political problems that arise during the game is one of its most valuable features"[25].

* The "future history" orientation of the games' output makes them an excellent vehicle for exploring response options in terms of the time sequences of coordinated action they imply. The requirement that such actions taken in the games be internally consistent, and that ways be found to sustain them in the face of new problems, other groups' policy agendas, and wavering social will has often proved to be among the most powerful tools of policy analysis[26].

* The political games helped to refine future research priorities for technical participants and their staffs by exposing them to the kinds of questions their political masters would need answered under a range of often unconventional but still plausible future histories. If experience with political exercises is any guide, we should expect that many of the ostensibly useful answers now being sought by scientists and analysts concerned with global environmental change are ones for which no policy people are ever likely to ask the relevant questions. Conversely, we are likely to find a number of urgent questions emerging in the course of the policy exercises that scientists could have studied, but haven't. I suggested earlier that such practically important but understudied questions might include "row assessments" of the net impact of policy actions across a range of atmospheric components. More generally, I suspect that the design of global environmental monitoring and data systems would benefit tremendously from such policy experiments.

In conclusion: The debate over global atmospheric change has now reached a stage at which further advances in coping with its practical implications will require much closer integration of political and environmental perspectives than has until now been the case. Some form of policy exercise, aimed at writing future histories of global atmospheric change and societies' responses to it, seems to offer the most likely prospects for fostering such integration. Over the next several years, several experimental policy exercises might profitably be conducted, each involving perhaps a dozen of the most informed and creative scholars and policy people concerned with global environmental change. The only way to discover whether we would really learn something useful from such an experiment will be to try it. At a minimum, I suspect it would be fun.

NOTES

1. See, for example, NRC (1988) and IGBP (1988).

2. The most concise statement of these central features is given by Schelling (1980), in a document that has substantially influenced the approach of this paper and on which I shall draw extensively. See also Clark (1986).

3. A large and increasingly perceptive literature exists on the uselessness of most forms of well- intentioned policy analysis. A smaller but more interesting literature has begun to confront the challenge of producing usable knowledge in the face on incomplete scientific understanding and politically fragmented messes (Lindblom and Cohen 1979; Wildavsky 1979). I deal with these issues in the context of development policy in Chapter 1 of Johnston and Clark (1982). World- scale "messes" are often termed "the global problematique".

4. The notion that incomplete science applied in policy contexts can usefully be viewed as a tool has been developed by philosopher of science Jerome Ravetz (1986).

5. Schelling (1983)

6. Cf. Crutzen and Graedel (1986), Darmstadter et al. (1987), Graedel and Crutzen (forthcoming) and Graedel (1989).

7. Clark (1985b)

8. Beanlands and Duinker (1983)

9. US National Research Council, 1981; Bolin and Cook, 1983; IGBP, 1988.

10. Jaeger 1983, National Research Council 1977, Bach et al. 1983

11. National Research Council 1979, 1981.

12. See, for example, Lindblom and Cohen (1979); Wildavsky (1979); Clark et al. (1979).

13. Schelling, 1983.

14. For a more complete application of this framework to the case of the greenhouse effect, see Schelling (1983) and Clark (1985a), and Jaeger (1988).

15. For discussions of policy analysis and applied science in general as "craft work" see Ravetz (1971), Wildavsky (1979) and Lindblom and Cohen (1979).

16. See Clark and Munn (1986), Toth (1986), Toth (1988a,b,c).

17. Brewer 1986

18. Goldhamer and Speier, 1959.

19. Brewer and Shubik 1979: 101.

20. Brewer, 1986.

21. Brown and Paxson 1975; Brewer and Shubik 1979.

22. Clark, 1985b.

23. Brewer, 1986.

24. Brewer and Shubik 1979: 101.

25. Goldhamer and Speier 1959: 77-8.

26. Schelling, 1984.

BIBLIOGRAPHY

American Meteorological Society. (1985). Planned and inadvertent weather modification: a policy statement. Bull. Amer. Met. Soc. 66: 447-449.

Bach, W., Crane, A.J., Berger, A.L., and Longhetto, A. eds. (1983). Carbon dioxide: current views and developments in energy/ climate research. Dordrecht: Reidel Publ.

Beanlands, G.E. and Duinker, P.N. (1983). An ecological framework for environmental impact assessment in Canada. Halifax, Inst. Environmental Studies of Dalhousie Univ. and Hull, Quebec, Federal Envir. Assessment Review Office.

Bolin, B. and Cook, R.B., eds. (1983). The major biogeochemical cycles and their interactions. Chichester, U.K.: John Wiley.

Brewer, G. (1986). Methods for synthesis: policy exercises. pp. 455-473 in Clark and Munn (1986).

Brewer, G. and Shubik, M. (1979). The War Game: a critique of military problem solving. Cambridge, MA: Harvard Univ. Press.

Brown, T.A. and Paxson, E.W. (1975). A retrospective look at some strategy and force evaluation games. R-1619-PR. Santa Monica, CA: The Rand Corporation.

Clark, W.C. (1985a). On the practical implications of the carbon dioxide question. WP-85-43. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Clark, W.C. (1985b). The cumulative impact of human activities on the atmosphere. In US National Research Council and Canadian Environmental Assessment Review Council. Cumulative environmental effects: a binational perspective. Ottawa: Ministry of Supply and Services.

Clark, W.C. (1986). Sustainable development of the biosphere: themes for a research program. pp. 5-48 in Clark and Munn (1986).

Clark, W.C., Jones, D.D., and Holling, C.S. (1979). Lessons for ecological policy design: a case study of ecosystem management. Ecological Modelling 7:1-53.

Clark, W.C. and R.E. Munn. (1986). Sustainable development of the biosphere. Cambridge: Cambridge Univ. Press.

Crutzen, P.J. and Graedel, T. (1986). The role of atmospheric chemistry in environment - development interactions. pp. 213-250 in Clark and Munn (1986).

Darmstadter, J. et al. (1987). Impacts of world development on selected characteristics of the atmosphere: an integrative approach. (2 vols.) ORNL/Sub/86-22033/1. Oak Ridge, TN.: Oak Ridge National Laboratory.

Goldhamer, H. (1973). Private communication to Brewer and Shubik (1979), quoted on their p. 103.

Goldhamer, H. and Spear, H. (1959). Some observations on political gaming. World politics 12: 72-83.

Graedel, T. (1989). Regional environmental forces: a methodology for assessment and prediction. Environment (forthcoming).

Graedel, T. and P.J. Crutzen. (forthcoming). Historical changes in concentrations of atmospheric constituents. In B. Turner et al., eds. The earth as transformed by human action. Cambridge: Cambridge University Press.

IGBP (International Geosphere-Biosphere Programme). (1988). The international geosphere-biosphere programme: a study of global change. A plan for action. Report No. 4. Paris: ICSU.

Jaeger, J. (1983). Climate and energy systems. Chichester: John Wiley & Sons.

Jaeger, J. (1988). Developing policies for responding to climatic change. WCIP - 1; WMO/TD - No. 225. Geneva: World Meteorological Organization.

Johnston, B.F. and Clark, W.C. (1982). Redesigning rural development: a strategic perspective. Baltimore: Johns Hopkins Univ. Press.

Lindblom, C.E. and Cohen, D.K. (1979). Usable knowledge: social science and social problem solving. New Haven: Yale Univ. Press.

National Research Council (1977). Energy and climate. Washington: National Academy Press.

National Research Council (1979). Nuclear and alternative energy systems. Washington: National Academy Press.

National Research Council (1981). Atmosphere-biosphere interactions: towards a better understanding of ecological consequences of fossil fuel combustion. Washington: National Academy Press.

National Research Council (1983). Changing climate. Washington: National Academy Press.

National Research Council (1988). Toward an understanding of global change: initial priorities for U.S. contributions to the IGBP. Washington: National Academy Press.

Ravetz, J.R. (1971). Scientific knowledge and its social problems. Oxford: Clarendon Press.

Ravetz, J. (1986). Usable knowledge, usable ignorance: incomplete science with policy implications. pp. 415-432 in Clark and Munn (1986).

Schelling, T.C. (1980). Letter report of the National Research Council's Ad Hoc Study Panel on Economic and Social Aspects of Carbon Dioxide Increase. Sent to Dr. Philip Handler, President, National Academy of Sciences. April 18, 1980.

Schelling, T.C. (1983). Climatic change: implications for welfare and policy. pp. 449-482 In National Research Council (1983).

Schelling, T. (1984). Private communication to the author.

Toth, F. (1986). Practicing the future: implementing the policy exercise concept. WP-86-23. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Toth, F. (1988b). Practicing the future, part 2: lessons from the first experiments with policy exercises. WP-88-12. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Toth, F. (1988b). Policy exercises: objectives and design elements. Submitted to Simulation and games.

Toth, F. (1988c). Policy exercises: procedures and implementation. Submitted to Simulation and games.

Wildavsky, A. (1979). Speaking truth to power: the art and craft of policy analysis. Boston: Little, Brown and Co.

Table 1: Definitions of valued atmospheric components and sources of disturbance: This table provides definitions of terms used in the text, adapted mainly from Crutzen and Graedel (1986).

Valued Atmospheric Components

Ultraviolet energy absorbtion: This property reflects the ability of the stratosphere to absorb ultravioloet solar radiation, thus shielding the earth's surface from its effects. This property is commonly addressed in discussions of "the stratospheric ozone problem".

Thermal radiation budget alteration: This property reflects the complicated relationships through which the atmosphere transmits much of the energy arriving from the sun at visible wavelengths while absorbing much of the energy radiated from earth at infrared wavelengths. The balance of these forces, interacting with the hydrological cycle, exerts considerable influence on the earth's temperature. This property is commonly addressed in discussions of "the greenhouse problem".

Photochemical oxidant formation: This property reflects the oxidizing properties of the atmosphere, caused by concentration of a variety of highly reactive gasses. The treatment here focusses on local scale oxidants that are often implicated in problems of "smog", crop damage, and degradation of works of art.

Precipitation acidity: This property reflects the acid- base balance of the atmosphere as reflected in rain, snow, and fog. It is commonly addressed in discussions of "acid rain".

Visibility degradation: Visibility is reduced when light of visible wavelengths is scattered by gasses or particles in the atmosphere.

Material corrosion: This property reflects the ability of the atmosphere to corrode materials exposed to it, often through the chloridation or sulfidation of marble, masonry, iron, aluminum, copper and materials containing them.

Table 2: Goals of policy response (Adapted from Schelling, 1983)

Alter Production

Energy management
- total use
- fossil fuel share
- fossil fuels with low C,S
- clean combustion

Land management
- forest conversion
- wetland conversion
- fertilization
- biomass burning

Ocean management
- biological pump
- fertilization

Other management
- industrial releases

Modify Environment

Thermal radiation budget
- greenhouse gases
- albedo

Water budget
- reservoirs
- river diversions

Chemical environment
- pH adjustment
- catalyze destruction

Recover Releases

Energy management
- scrubbing stack gases
- disposal problems

Land management
- change forest area
- change forest density
- fertilize trees
- change wetland area

Ocean management
- prime biological pump

Other management

Adapt to Change

Agriculture
- change land use
- change crops
- improve crops
- improve trade
- change diet

Habitation
- migrate
- "air conditioning"
- protective clothing
- sea level adjustments

Other adaptations
- construction
- transport
- military operations
- compensation

Figure 1: Environmental assessment and policy goals

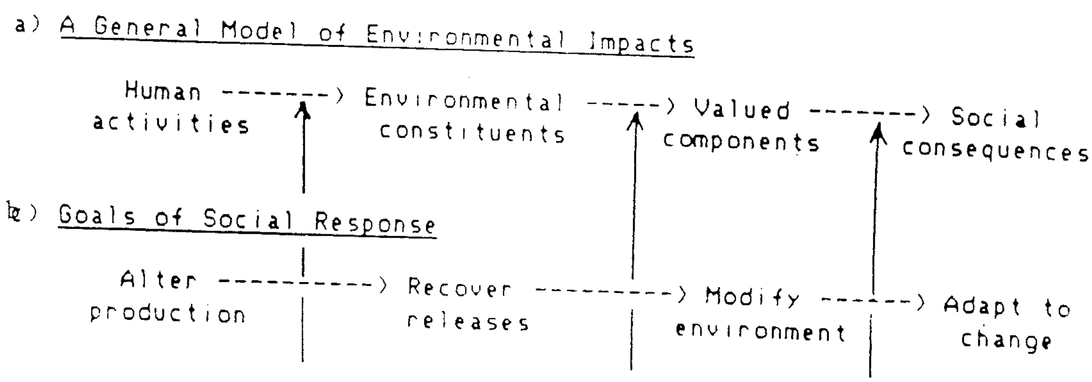

Figure 2: A synoptic framework for environmental assessment (from Crutzen and Graedel, 1986)