Cybernetics of Global Change:

Human Dimension and Managing of Complexity

by
Mihajlo D. Mesarovic
David L. McGinnis
Dalton A. West

"The challenge in bridging the gap between science and decisionmaking is in blending reasoning with vision."
Federico Mayor, Director General of UNESCO

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About the authors

Mihajlo D. Mesarovic*

Mihajlo D. Mesarovic, a member of the Club of Rome, is Cady Professor of Systems Engineering and Mathematics at Case Western Reserve University in Cleveland (Ohio), and UNESCO Consultant for developing and directing the Globally-oriented Universities Education Consortium. He has done research on complex systems and the global problematic and authored a number of books, including *Abstract Systems Theory* (1994), *General Systems Theory: Mathematical Foundation* (1980), *Mankind at the Turning Point, Second Report to the Club of Rome* (1974). He has also been a consultant to governments, international organizations and the private sector on decision support for top executives, global issues analysis and strategic planning.

Case Western Reserve University
Crawford Hall, 6th Floor
10900 Euclid Avenue
Cleveland, Ohio 44106
Phone: 216/368-4466
FAX: 216/368-3123

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David L. McGinnis

David L. McGinnis is a Research Associate with the Cooperative Institute for Research in Environmental Sciences at the University of Colorado. His research topics range from General Circulation Models Simulation of Arctic Climate to possible change in Western United States water resources emanating from high altitude snowpack. Working at the interface between physical and social sciences, he attempts to add human dimensions to climate research topics.

University of Colorado
Boulder, Colorado

About the authors

Dalton A. West

Systems Applications, Inc.
Annandale, Virginia

Dalton A. West is Vice-President of the United States Global Strategy Council. He writes and lectures on global strategic problems, particularly in the Asia-Pacific and the former USSR, and has experience in lecturing at Colleges and universities in the United States, Canada and the Asia Pacific.

Table of contents

Preface

One of UNESCO's major missions is to promote closer linkages between scientific knowledge and policy-making.

The work of Mihajlo D. Mesarovic, David L. McGinnis and Dalton A. West, that we have the pleasure of publishing in the MOST Policy Paper Series, is an important contribution to the effort the Director-General of UNESCO, Frederico Mayor, qualified as "bridging the gap between science and decision-makers". The authors propose a new paradigm, applied in this case to the area of global change, but which can be adapted for application in other important fields, such as population, migrations, employment, etc.: It aims at replacing the input/output paradigm, generally used in research and policy analysis, by a paradigm the authors refer to as cybernetic and reflexive. In their words, what is proposed is an "integrated assessment, as a process of reasoning about the global future, based on decision support methodologies in which an ensemble of models are used and the human factor is "put inside the models", to represent goal-seeking (adaptive) behaviour and account for non-mesurable aspects".

A prototype of an integrated assessment support system, named GLOBESIGHT (a contraction of Global Foresight) has been developed, and is used in various circumstances, and in particular the following UNESCO activities: a series of "UNESCO Workshops on Bridging the Gap Between Science and Decision-Making", as well as the "Globally-Oriented University Education Consortium", that UNESCO has recently launched, with the aim of fostering teaching and research on global issues through a network of universities in different parts of the world, including the Case Western Reserve University (USA), Bilkent University (Turkey) and the Technical University of Catalunya (Spain). Others, such as the Trier University (Germany), Jawaharlal Nehru University (India) and Autonomous University of Mexico (UNAM) are about to join the network.

Also, in December 1995, the MOST programme and the Institute of World Systems, Economies and Strategic Research of Bilkent University, jointly organized an international symposium in Ankara, on "Methodological Issues, Quantification Techniques, Decision-making and Governance in Social Sciences", where GLOBESIGHT was presented and major epistemological and methodical issues involved in this field were discussed. A book is in preparation.

This Consortium, directed by M. Mesarovic, is developed within the context of UNESCO's Management of Social Transformations Programme (MOST), University Twinning Programme (UNITWIN) and Co-ordination Unit for the Environmental Programmes - the latter being the International Geological Correlation Programme (IGCP), International Hydrological Programme (IHP), International Oceanographic Commission (IOC) and Man and the Biosphere Programme (MAB). Currently, there are also efforts to disseminate a simpler version of this paradigm and the GLOBESIGHT model, at the secondary education level, particularly through the UNESCO Associated Schools network, which involves schools throughout the world.

Ali Kazancigil
Director, Division of Social
Sciences, Research and Policy
Executive Secretary,
MOST Programme
UNESCO, Paris, April 1996

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1 Cybernetic Paradigm[1] for the Human Dimension

Understanding the role which humankind plays in global change is a prerequisite for the development of realistic and credible policies for mitigating change. That role is customarily described in terms of the "human dimension". The very term "dimension" itself indicates the inadequacy assigned to the human role. One would not characterize the role of natural phenomena in analogous terms, e.g., by talking about the "ocean dimension" or "atmosphere dimension" of global change. Atmosphere, oceans, land, and other natural systems are clearly subsystems which constitute a global system through interaction. Similarly humankind is also a subsystem which, like any of the natural subsystems, is a constituent part of the global system. This is not recognized in research under the so-called "human dimension", which focuses on two sets of indicators:

- the impact of anthropogenic activities on the environment, e.g., the increase in greenhouse gases, and resulting changes in the atmosphere and climate, etc.; and

- the impact of environmental change on humans, e.g., changes in agricultural productivity under assumed change in the atmosphere, etc.

What is missing, however, *is how these two categories of indicators are related* or how these two sets of indicators are connected, i.e., how the human system *functions in time* as the global change occurs. This requires:

1. *The paradigm is referred to in the sense of: Norbert, Wiener.* Cybernetics or Control and Communication in Machines and Animals, *Cambridge, Mass., MIT Press, 1948.*

- a proper representation of the process of interaction between humankind as a system and the natural system; and
- explicit recognition of the specific and unique character of human functioning as a system.

2. *George Soros,* Alchemy of Finance, *Simon & Schuster, New York, 1987.*

3. Earth Systems Science: A Program for Global Change, *Washington, DC, 1989.*

The first aspect - the relationship of humankind with nature - is best understood in terms of the reflexivity concept amply advocated by George Soros[2]. Simply put, humanity is changing the environment while *simultaneously* being changed by it. It is a continuous feedback relationship. Humans are not outside observers of global change but rather are on the inside of the system being changed. This imposes a fundamental uncertainty (a limit to complete, objective knowledge or predictability), a "bias" in Soros' terminology. The human dimension view, illustrated in Fig. 1 has to be replaced with the reflexivity view illustrated in Fig. 2. The human impact and the impact on humans cannot be considered separately but as clearly related (connected) in real time. Understanding this reflexive, feedback configuration of the global change system is central to understanding the human role in global change. Currently, human dimension research focuses on the study of historical and present data - economic, demographic, land use, social indicators, etc. - and also on anthropological studies of the self-sustaining existence of tribes (present or past) in isolated parts of the world. While this research is certainly of interest and instructive, it is not adequate to address the predicament facing global society in the 21st century. Fig. 3 compares the view of the global change system by the Earth Systems Science Committee[3] and the view based on the reflexivity concept.

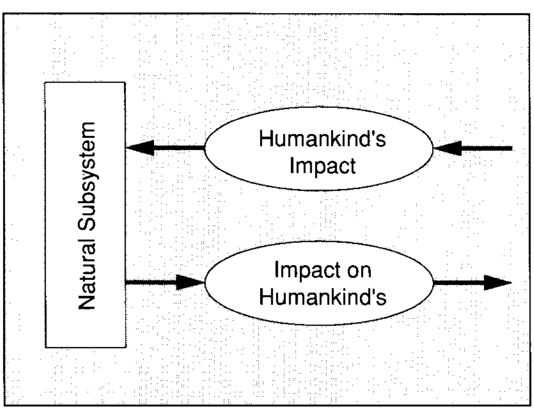


Figure 1

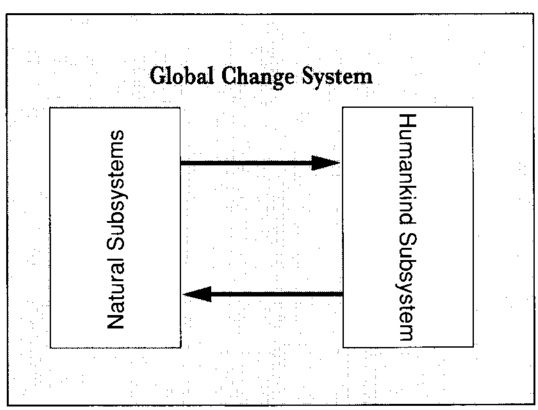


Figure 2

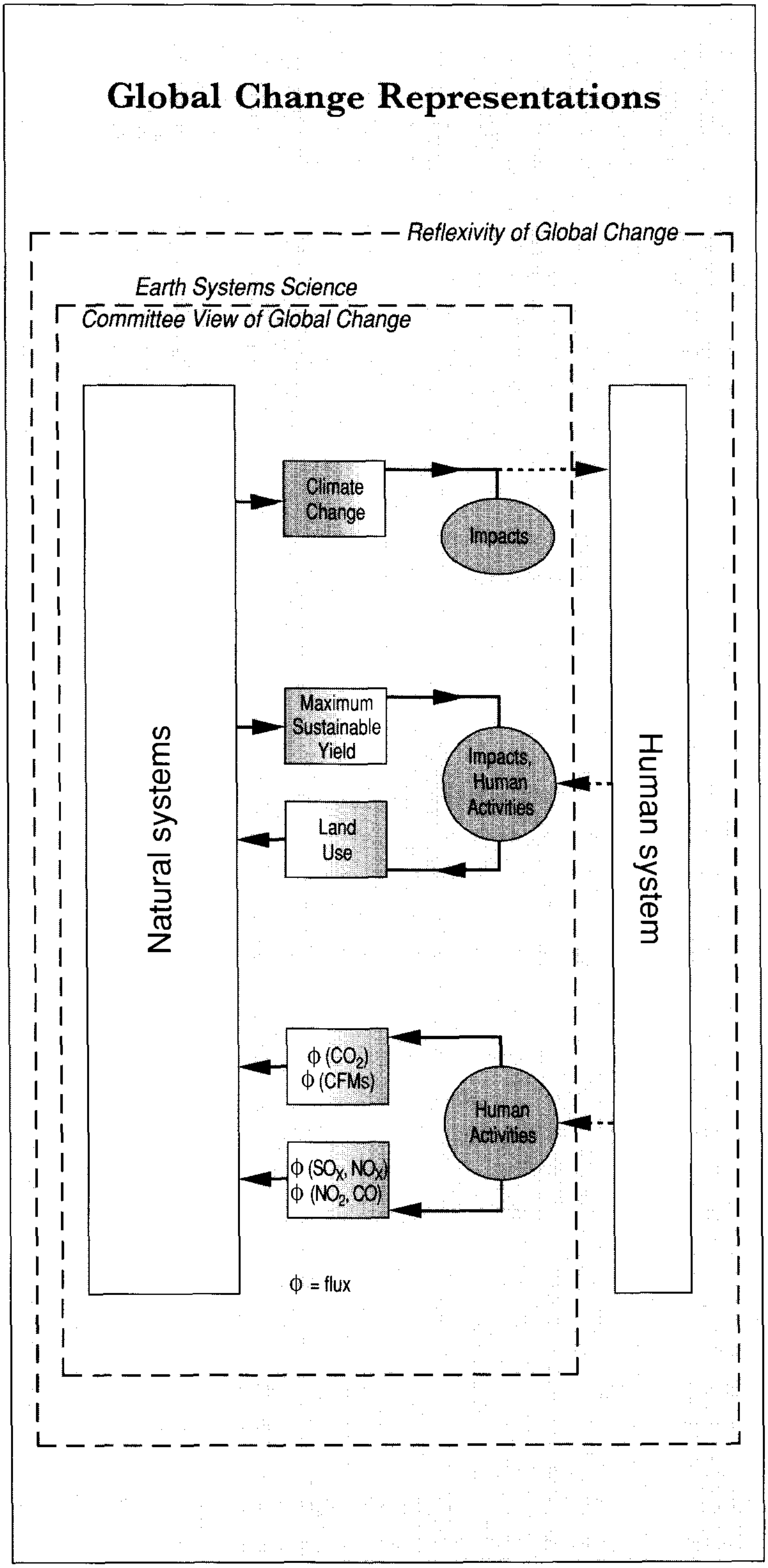

Global Change Representations
Reflexivity of Global Change
Earth Systems Science
Committee View of Global Change
Natural systems
Climate Change
Impacts
Maximum Sustainable Yield
Impacts, Human Activities
Land Use
φ (CO2)
φ (CFMs)
Human Activities
φ (SOX, NOX)
φ (NO2, CO)
φ = flux
Human system

Figure 3

The second aspect - proper representation of the specific character of humankind and the role it plays in global change - needs a paradigm different from the input/output or state transition paradigm used thus far in the study of global change. In the state transition paradigm the system is assumed to be fully describable in terms of the state of the system at a given time and the system transformation (mapping, transfer functions) of that state to another state as well as the input between two instances in time. This paradigm originated in physical sciences. To convey the true nature of such a paradigm we refer to it as the "Newtonian mechanics" paradigm. It assumes that only lack of data and knowledge prevents us from being able to fully predict the future; there is no room for uncertainty or indeterminism. The state transition (input/output, stimuli/response) view can be useful under limited circumstances in the representation of humankind as a subsystem but erroneous if overextended. Using this paradigm, models (economic, energy, integrated, etc.) are developed in terms of differential (or difference) equations with or without equilibrium processes. It has been observed that the problem with such models is not that their predictions are wrong, but that they are right most of the time *except when the predictions are really needed.* If the time horizon is short and "business as usual" prevails the prediction using input/output paradigms does not go far wide of the mark. It is when the change is sufficiently large and the consequences are felt over a sufficiently long period of time that the input/output paradigm breaks down.

An alternative to state transition is the goal-seeking (or decision-making) paradigm. It has its origin in biology and the study of human behavior rather than in physical phenomena. More concisely, the functioning of the system in the goal-seeking paradigm is represented by two items:

- goal(s) of the system; and
- the processes which the system possesses to pursue these goals and to respond to the influences from the environment.

The state transition and goal-seeking paradigms can be more explicitly and precisely contrasted in terms of mathematical general systems theory[4].

In the framework of state transition, input/output representation of a system is considered as consisting of a pair of transformations (mapping, transfer functions), namely, *state transition,* S1, and *output function,* S2.

4. *Mihajlo Mesarovic and Yasuhiko Takahara,* Mathematical Theory of General Systems, *Academic Press, 1974; Mihajlo Mesarovic and Yasuhiko Takahara,* Abstract Systems Theory, *Lecture Notes in Control and Information Sciences, eds. M. Thoma and A. Wyner, Springer-Verlag, Berlin, Heidelberg, 1989.*

$$S1 : Z_t \otimes X_{tt_1} \rightarrow Z_{t_1} \qquad 1$$

$$S2 : Z_{t_1} \rightarrow Y_{t_1} \qquad 2$$

where X_{tt_1} is the set of inputs in the time interval between t and t_1, Y_{t_1} is the set of outputs at t_1, Z_t and Z_{t_1} are states at the times t and t_1, respectively, and f (the Cartesian product) simply indicates that the variables before the arrow (inputs) are causes for the change in the variables after the arrow (outputs). The equations simply state that given a state of the system $z \in Z_t$ and an input x $x_{tt_1} \in X_{tt_1}$, the next state $z_{t_1} \in Z_{t_1}$ is fully predictable (Eq. (1)) resulting in a predictable output $y_{t_1} \in Y_{t_1}$ (Eq. (2)). To understand the system one has to have data on Z and X and the knowledge of S_1 and S_2.

The goal-seeking paradigm requires more items. The following are needed for representation of the system in the most general case:

- A range of alternative actions (decisions), M, available to the system in response to what is happening or is expected to happen in the system's environment.

- A range of uncertainties, U, which the system envisions as possibly affecting the success of the selected decision. The uncertainties can be due to two sources:
- uncertainty as to what might happen in the environment, i.e., the external input from a range of anticipated inputs; and
- uncertainty due to an incomplete or inaccurate view (representation, image) of what the outcome of the decision will be even if the external input is correctly anticipated. This represents the bias on the part of the goal-seeker as to how the overall system functions. For example, if the first kind of uncertainty is resolved in the sense that the environmental input is exactly as expected, the outcome can still be uncertain because of the lack of knowledge on the part of the decision system as to how the environment is going to react to the decision.

- A range of consequences (outputs) following implementation of the system's decision, Y.

- An evaluation set ("performance scale"), V, used by the system to compare the results of alternative actions; i.e., given the outcomes of the two decisions, which of the two is preferable.

- The decision system's view of the environment; i.e., what is the system's understanding of the environment. In other words, what output (consequence), y from Y, the system expects after a decision, m out of M, is implemented and the environmental influence, u in U, is correctly anticipated. In reality, it is seldom, if ever, a complete and accurate reflection of the reality. In general terms, the corresponding mapping, P, is given by

$$P : M \otimes U \rightarrow Y$$

- An evaluation mapping, G, used to compare the outcomes of the decisions using the preference scale, V, and taking into account the "extent or cost of the effort", i.e., m in M. This is also a mapping

$$G : Y \otimes M \rightarrow V$$

for any given m in M resulting in y in Y. The mapping, G, assigns a value, v in V. The role of G is to determine the system's preference for a pair (mi, yi) over another pair (mj, yj).

- The tolerance function (relation) which indicates the degree of satisfaction with the outcome if a given uncertainty, u in U, comes to pass

$$T : U \rightarrow V$$

For example, if the conditions are of full certainty, the best (i.e., optimal decision) can be identified. If, however, there are several events which are anticipated (i.e., U has more than one element) the performance of the system, as evaluated by G, can be allowed to deteriorate for some u in U, but it must stay within a tolerance limit which will ensure "survival of the system".

- Using the above items the functioning of the system is defined by the statement:

Find a decision ($\hat{m}$) *in M so that the outcome is acceptable (e.g., within the tolerance limits) for any possible occurance of the uncertainty u in U, i.e., find* ($\hat{m}$) *in M such that*

$$G(P(\hat{m}, u), \hat{m}) \leq T(u, \hat{m})$$

for all u in U.

This formulation is intimately related with what Herbert Simon introduced as satisfactory (bounded rationality) human behavior[5] in contrast to the "economic man" (i.e., optimizing) view which dominates economic theory.

5. *Herbert Simon,* Models of Man, *J. Wiley, 1976.*

An important role in this formulation is explicit recognition of uncertainty and the concept of tolerance (acceptability, survival). The performance can deteriorate for extreme occurrances in the environment but it can still be acceptable or satisfactory (the outcome being within tolerance limits) if "survival" of the system is assured regardless of what occurs within the range of anticipated occurances.

Several remarks are helpful in clarifying the contrast between the two paradigms:

- The input/output paradigm is far easier to model and should be legitimately used whenever it does not result in a large distortion of reality. However, if the behavior of the system is truly purposive, i.e., goal-seeking, this might not be possible. An illustration of this can be found in the computer programmes for theorem proving, chess playing and the likes. These programmes are not developed in terms of state transitions but rather in terms of the so-called end-means, i.e., in terms of goals (ends) and processes (means) to pursue these goals.

- The need for a new, human-based paradigm is recognized even in well-established fields such as economics. Kenneth Arrow[6] has recently observed *"...the very notion of what consititutes an economic theory may well change. Some economists have maintained that biological evolution is a more appropriate paradigm for economics than equilibrium models analogous to mechanics."*

6. *Kenneth Arrow,* Science, *March 17, 1995, pg. 1617.*

Formalization of the goal-seeking paradigm briefly outlined above provides a basis for a deeper theory of the "human dimension" of global change, as well as for other phenomena where recognition that humans are not inert physical objects (machines) is essential[7].

7. *Y. Takahara, B. Nakano and K. Kijima,* Characterization of the Satisfactory Decision Principle, *J. of the Oper. Res. Soc. of Japan, Vol. 21, No. 3, 1978; Y. Takahara, B. Nakano and K. Kijima,* A Structure of Rational Decision Principles, *Int. J. of Systems Science, Vol. 7, 1981.*

- Input/output representation appears to be simpler in the sense that it requires fewer items to be described. This, however, can be misleading. If the system is truly goal-seeking the *input/output representation depends on the range of environmental influences (inputs).* Under different circumstances (different category of inputs) the input/output representation becomes different. The system appears to "switch" from one mode of behavior to another (e.g., in the so-called self-organizing systems). If the environmental change is extensive, a large number of alternative representations are needed with the system appearing to switch, in time, from one mode of behavior to another. On the other hand, if the goal-seeking representation is achievable, it remains invariant over a large range of environmental inputs.

- Goal-seeking representation requires a deeper understanding of the system and is often difficult, if not prohibitive. *However, even if the input/output description(s) has to be used, the results of the analysis should be interpreted in reference to the true paradigm of the system.*

2 Human as a Submodel

Accepting the need for a reflexive and goal-seeking representation of humankind in global change, the question is how this can be realized. One approach is to develop computer algorithms which represent the processes which the goal-seeking system uses to pursue its goal. This is within the domain of so-called artificial intelligence. Another approach being considered at present consists of *putting the human inside the model.* Rather than simulating goal-seeking behavior by computer algorithms, the human (user) is put in the position of being an integral part of the model (a component, subsystem) representing goal-seeking (decisionmaking) behavior (within the decisionmaking framework represented by Eq. 3-6). The human is in a reflexive relationship with the computer models of the natural systems. One way to look at this is to view the human as being in a "game" type, interactive relationship with the computer algorithm parts of the model. The human/computer inter-linkage is "tight" in the sense that the computer model *cannot* evolve in time unless the user "simulates" the functioning of the humankind system. The architecture is that of a blended simulation/gaming process. It is not pure simulation because the computer components of the total model cannot proceed to the next step without the human's actions and it is not pure gaming in the sense that the human action is deeply imbedded in the structure of the overall system (model) - it merely represents the subjective view of humans as to how humankind responds to changes in the environment[8]. A brief

8. The time interactive approach to incorporate human into a model is analogous to the organizational behavior pointed out by a number of authors. They argued that policy decisions are mired in an incremental approach and that policymakers tend to muddle through and redefine goals when expectations are unrealized. In such approaches a range of policy alternatives are considered, resulting in a set of satisfactory (acceptable) policies (bounded rationality) rather than the "best" policy. It is then left up to the decisionmaker (user) to decide which of the alternative policies to pursue on the basis of risk aversion, rules-of-thumb, conflict avoidance and the likes. See for example:
- *H. Von Storch, Inconsistencies at the Interface of Climate Impact Studies and Global Climate Research,* Meteorol. Zeitschrift, *N.F. 4, pp. 72-80, April, 1995;*
- *J. Rees,* Natural Resources: Allocation, Economics and Policy, *Second Edition, Rutledge, New York, 1990;*
- *G.T. Allison,* Essence of Decision: Explaining the Cuban Missile Crisis, *Little, Brown, Boston, Mass., 1971;*
- *H. A. Simon, A Behavioral Model of Rational Choices,* Quarterly Journal of Economics, *Vol. 69, February, 1955, pp. 99-118;*
- *C. E. Lindblom, The Science of Muddling Through,* Public Administration Review, *Vol. 19, 1959, pp. 79-99.*

description of such an interaction in reference to time evolution is given in Box 1 and Figs. 4a and 4b.

Implementation of such human/computer modeling goes beyond the time interactive process. The challenge of developing such symbiotic, human/computer models consists fundamentally of carefully distinguishing where human intuition, vision, views on uncertainty, etc., (subjective aspects) are needed from where the logic, numbers, and facts (objective aspects) are used for deeper computer analyses. As an illustration, delineation of human computer roles in conflict resolution among multiple objectives (a crucial issue in global change) is described in Box 2 and Fig. 5.

Symbiotic human/computer modeling provides a framework to take into account non-numerical (non-measurable) aspects of reality. The omission of non-measurable aspects can lead to a major distortion of the representation[9].

3 Multilevel versus Integrated Modeling

The need to represent phenomena from different scientific disciplines in the modeling of global change leads to the concept of integrated modeling in which all relevant disciplines are taken into account. Early integrated models (more than twenty years ago) addressed resource/population issues[10] while, more recently, the emphasis has been on climate change[11]. A straightforward ("brute force") approach to integrated modeling consists of developing models in the respective disciplines and then linking them together without due regard as to how much is known about the linkages. There are serious shortcomings to such an approach which can greatly diminish the faithfulness of the constructed model. Views have been expressed that an integrated model is as good as its component submodels. The problem of the validity of such an integrated model goes much beyond that. The key problem is in the linkage which integrates the submodels into the overall integrated model. While the phenomena within disciplines could be modelled with a degree of confidence, linking disciplinary models is highly conjectural. The interdependence of the phenomena between different disciplines can be viewed as one

9. A telling quote indicating the dangers of ignoring non-measurable aspects of reality was attributed to Daniel Yankelovich in D. Katzner, Analysis Without Measurement, *Cambridge University Press, 1985:* "The first step is to measure whatever can be easily measured. This is okay as far as it goes. The second step is to disregard that which can't be measured or give it an arbitrary quantitative value. This is artificial and misleading. The third step is to presume that what can't be measured easily really isn't very important. This is blindness. The fourth step is to say that what can't be easily measured really doesn't exist. This is suicide."

10. Mihajlo Mesarovic and Eduard Pestel, Mankind at the Turning Point, *Dutton/Reader's Digest, 1974.*

11. See, for example:
- *Jae Edmonds and F. Reilly, Global Energy:* Assessing the Future, *Oxford University Press, 1985.*
- *A. Manne and R. Richels,* Buying Greenhouse Insurance: The Economic Costs of Carbon Dioxide Emission Limits, *Cambridge, MA, MIT Press, 1992.*
- *Y. Matsuoka, et al., Scenario Analysis of Global Warming Using the Asian-Pacific Integrated Model (AIM),* in Integrative Assessment of Mitigation, Impacts, and Adaptation to Climate Change, *N. Nakicenovic, W.D. Nordhaus, R. Richels, and F.L. Toth, eds., 1994.*

Box 1

In order to blend subjective (humanistic, non-numerical) aspects of the future and to avoid projection of the past into the future in a "mechanistic" fashion governed exclusively by a model, symbiotic interactive processes of scenario formulation and assessment are used in the workshops. In traditional scenario analysis the assumptions and policy options are selected at the beginning of the model run and the future is determined from the initial time until the end of the entire policy time horizon solely by the fixed structure of the computer model and parameters estimated from the past data trends (Fig. 4a). In the interactive process used at the workshops (Fig. 4b) the future course is outlined in time increments; the human is but a submodel on par with the computer algorithms. The process starts with the implementation of present policies and assumptions about uncertainties over a relatively short time increment (although the long-term view is taken into account as needed in making the incremental assumptions). The computer programme portion of the model generates feasible consequences of the policies and assumptions at the end of the first increment. The human then makes new policy choices and assumptions for the second time increment on the basis of the newly arrived at state of the system at the end of the first time increment. In response, the computer generates the state of the system at the end of the second time increment providing a basis for policy consideration by the human for the next time increment. The process proceeds iteratively until the end of the entire policy time horizon. Computer algorithms (models) do not predict the future in such a process but rather have the role of consistency checks to make the vision and goals of the human consistent with the facts (reality).

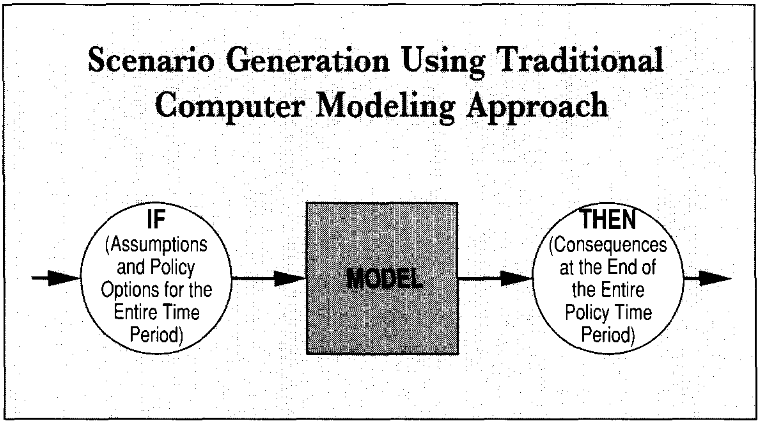
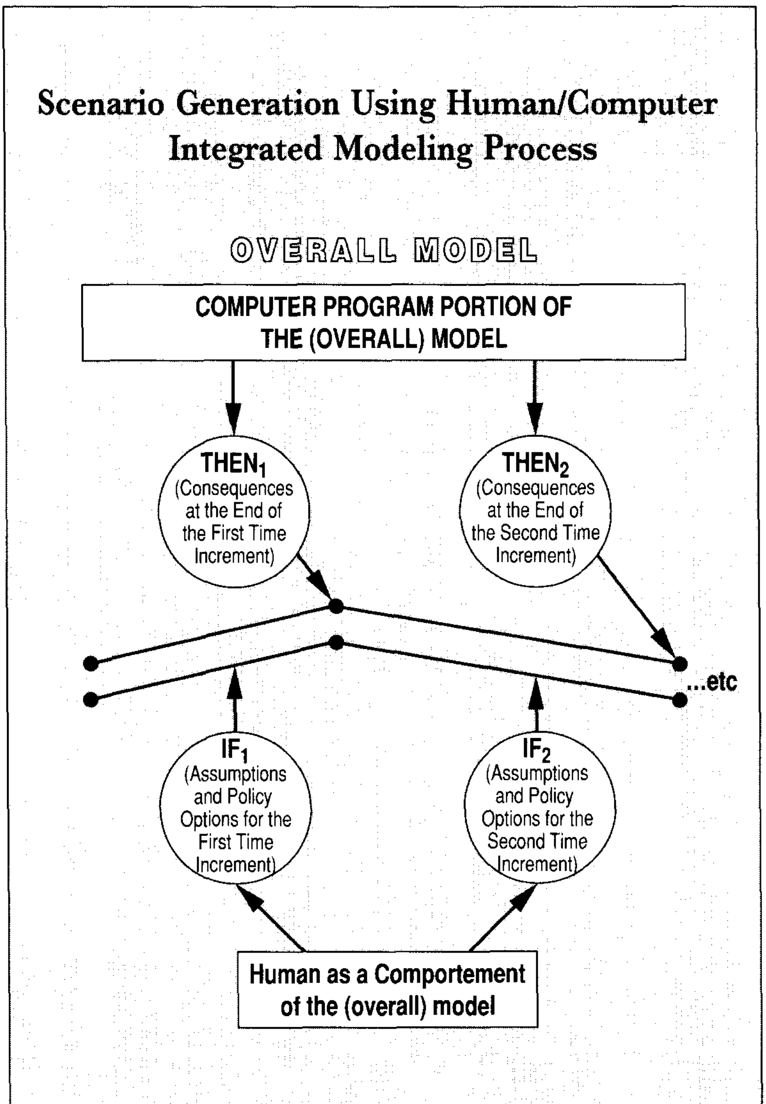


Figure 4a

Figure 4b



Box 2

In policy development for complex societal problems, it is essential to recognize the existence of competing, conflicting, objectives which have to be taken into account simultaneously. For example, economic growth, unemployment, trade, etc., have to be harmonized with the environmental concerns (e.g., increase in concentration of greenhouse gases). A solution to this dilemma is achieved by a careful delineation of responsibility between the computer and the human - the former contributing efficient logical procedures, the latter providing values preferences and subjective judgements. The process is shown in Figure 5. The process starts with the human specifying a range of alternative policy options to which the support system (computer) responds by outlining the corresponding evolution of the system for each of the policy options. An initial set of alternative scenarios is generated. In the next step, the user specifies the (conflicting) objectives which provide a basis for the support system to eliminate all "inferior" scenarios. A scenario, A, is inferior if there exists another scenario, B, in the set, such that B is preferable to A with respect to all objectives. The surviving scenarios represent the set of non-inferior (mutually conflicting) scenarios. A set of non-inferior scenarios is much smaller than the initial scenario set. This reduced set contains only conflicting scenarios in the sense that there is no scenario which has the best performance in all objectives. The user then specifies the tolerable (acceptable) level of performance for all objectives which allows the support system to reduce the set of scenarios to a still smaller set of "satisfactory" scenarios all having acceptable levels of performance. To make the final choice an ensemble of "conflict resolution principles" are available. They differ in the way the user's views are explicitly taken into account. On one end of the spectrum is a procedure in which the user indicates preferences among conflicting objectives by assigning the relative Weight (importance) to different objectives.

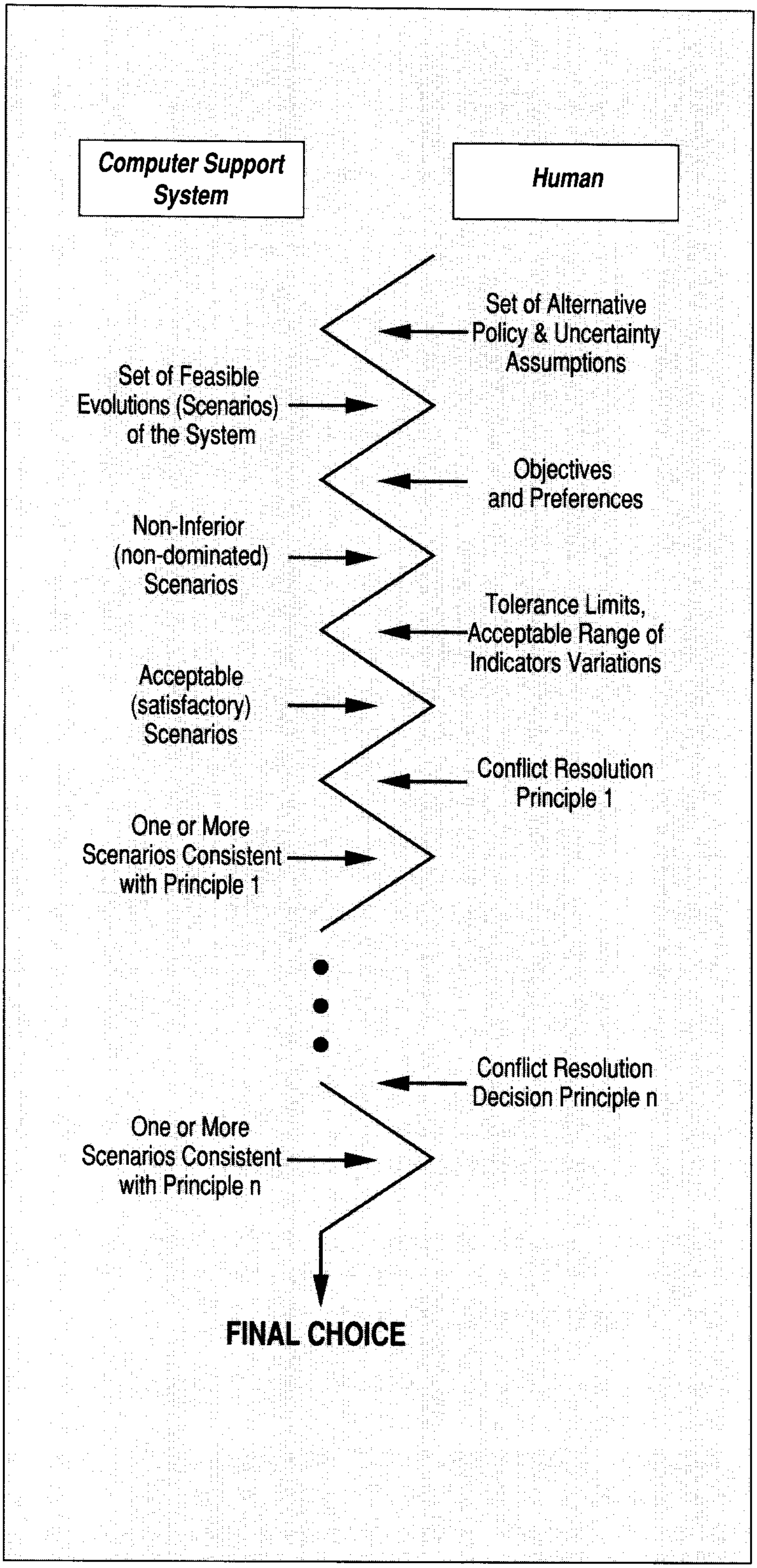

Computer Support System
Human
Set of Alternative Policy & Uncertainty Assumptions
Set of Feasible Evolutions (Scenarios) of the System
Objectives and Preferences
Non-Inferior (non-dominated) Scenarios
Tolerance Limits, Acceptable Range of Indicators Variations
Acceptable (satisfactory) Scenarios
Conflict Resolution Principle 1
One or More Scenarios Consistent with Principle 1
Conflict Resolution Decision Principle n
One or More Scenarios Consistent with Principle n
FINAL CHOICE

Figure 5

The computer then takes over and identifies the implied choice of policy. On the other end of the spectrum, where human judgement is given a major role an interactive conflict resolution process is used. In the process the user compares the scenarios pair-wise and indicates the preference between them. The process starts by presenting the user with two conflicting scenarios. The user is then requested to select the preferable scenario. The choice is made not only on the basis of the extent of contlict in the objectives, but also keeping in mind a whole range of other factors. The survived scenario is then paired with another scenario from the acceptable set. The human again selects the preferable one. While the process of pair-wise comparisons proceeds, the computer deduces the preference scale from among the satisfactory but mutually conflicting scenarios of the human on the basis of the choices which the user is making. The support system then indicates the final choice on the basis of the user's deduced preferences. To avoid being "boxed-in" by the computer procedures, a large number of different conflict resolution principles are often used. The final choice is made by the human in reference to which of the conflict resolution principles intuitively yields the most appealing outcome.

of the "ultimate" challenges to science. Creating an integrated model poses the danger of misrepresentation due to:

- *Burying the lack of knowledge deep within the model structure* making it more difficult to understand what contributes to the overall (integrated) model behavior;

- *Conveying the impression of certainty* where it does not exist; and

- *Resulting in fundamentally different behavior of the integrated model from the behavior of the real system in spite of the faithfulness of the submodels.* Even the simple links between well-defined, fully determinate models can lead to fundamentally different behavior. This can easily be illustrated[12].

12. *A. Ichikawa,* Plenary Lecture, *U.S./Japan Symposium on Integrated Assessment, Honolulu, Hawaii, 1994.*

Consider two of the simplest possible systems described by the equations:

$$x_1(t+1) = -ax_1(t) - x_1(t)^3 + y_1(t) \qquad 7$$

$$y_2(t+1) = bx_2(t) \qquad 8$$

where the indices 1 and 2 refer to the fact that the same variables are recognized in two separate scientific domains. Recognizing that they refer to the same real-life variables (although in different scientific domains), the integrated model takes the form

$$x(t+1) = -ax(t) - x(t)^3 + y(t) \qquad 9$$

$$y(t+1) = bx(t) \qquad 10$$

While the two submodels are apparently quite well-behaved with fully predictable future trajectories, the integrated model for certain values of parameters (e.g., $a = 2.1$ and $b = .04016$) becomes chaotic, i.e., indeterminate and fully unpredictable. When the submodels are themselves complex *it is not possible with any degree of certainty to know whether the resulting integrated model produces a fundamentally different behavior from that observed in real life.* Even a simple and weak linkage (as given in the above example) can fully destroy the faithfulness of the overall model in spite of submodels being consistent with reality.

The important question in integrated modeling is how plausible it is that the representation will not be distorted by the linkages. This question needs careful scrutiny even in modeling of physical systems, such as in linking atmosphere and ocean models, not to mention models involving humans.

Other shortcomings of integrated climate change-focused models is that they do not provide the possibility of accounting for the human goal-seeking behavior. A set of numbers and fixed mapping functions are used throughout the model to represent the results of complex and uncertain individual and societal processes. A simple example is the use of elasticities in economic modeling to represent the outcome of exceedingly complex decision processes. A small set of numbers - values of elasticities - stand for the reaction of individuals and societies to change (e.g., energy consumption relative to prices). Although the elasticity relationships are empirically established from the past data, their validity over future time horizons depends on human decisions (individual and societal) yet to be made. Justification for relying on elasticities to encapsulate human behavior depends on the time horizon, magnitude, rate and character of change.

An alternative to integrated modeling by the "hard wired" linking of computer programs is the *multilevel integrated modeling approach* which consists of four steps:

- Development of a multilevel, conceptual framework which will indicate the relative position (role) of the disciplines and indicate the linkages needed.

- Construction of the models within the disciplines represented.

- Linkage of the disciplinary models using either coded links where the available knowledge is justified or *via the user where the links are conjectural* or have to be carefully monitored.

- Development of a goal-seeking framework to incorporate the human inside the model.

A multilevel framework currently being used to research cybernetics of global change is shown in Fig. 6. The highest level represents the individual's perspective (needs, values, etc.) The next, so-called societal (or group), level represents formal and informal organizations in reference to the problem domain for which the model is built. The central level encompasses economics and demography - an "accounting" view. Underneath this level is the representation in physical terms, i.e., in terms of mass transfer and energy flows (metabolism). At the very bottom, there is the level of natural, ecological/environmental processes.

Several remarks should be made in reference to the multilevel framework:

- The architecture shown in Fig. 6 is only one of several possible alternatives. Important to the approach is not whether the structure shown in Fig. 6 is the right one, but rather that a multilevel structure should be constructed as the first step in integrated modeling of complex systems.

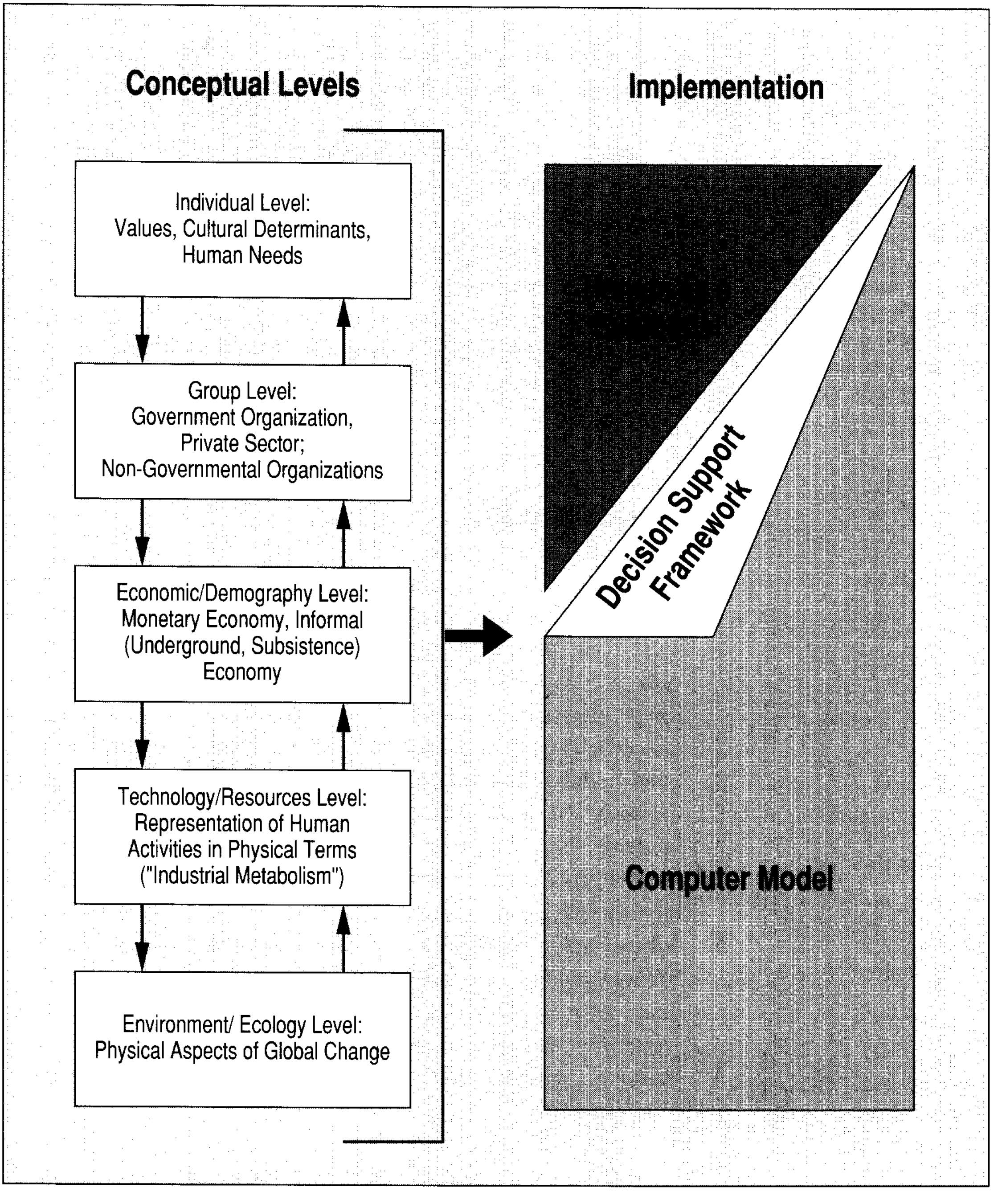


Figure 6

- The multilevel architecture provides the basis for including the human inside the model. First, *the linkages between and within levels which are uncertain are controlled by the human who can experiment with alternatives to establish the most plausible relationships under the circumstances.* Second, *the human represents (simulates) the appropriate functions on the levels where the goal-*

seeking paradigm is called for. In particular, functioning on the higher levels is not amenable to state transition modeling and the human takes on the role of a submodel.

- Using the multilevel approach helps avoid the misdirected efforts to model various phenomena which do not fit the state transition paradigm. The best examples, perhaps, were the attempts to model political processes which lead to the most implausible conclusions[13]. Actually, only phenomena which are modelable by state transition should be modeled as such. All uncertain phenomena or processes which cannot be modeled numerically should not be included in the state transition type of models.

13. *S. Bremer, ed.,* The GLOBUS Model: Computer Simulation of Worldwide Political and Economic Development, Westview, *Boulder, Colorado, 1987. Runs of the GLOBUS model in the 1980s predicted the political system in Rumania to be more stable than that in Western Europe.*

4 Complexity

The multilevel approach helps in the management of complexity. Integrated modeling leads to ever more complex models for two reasons: first, by linking already large disciplinary models; and, secondly, in order to resolve uncertainty an increasing number of details are introduced in the models. However, *uncertainty and complexity are two different obstacles to understanding* which should not to be confused; instead they should be addressed in different ways. Making representation of a real system more complex does not diminish the underlying uncertainty; rather it merely obscures the source of the lack of understanding. As Herbert Simon[14] pointed out: *"Forty years of experience in modeling systems on computers, which every year have grown larger and faster, have taught us that brute force does not carry us along a royal road to understanding such systems... modeling, then, calls for some basic principles to manage this complexity."*

14. *H. Simon,* Operation Research Journal, *1992.*

Actually, in a number of instances a simple projection of trends is not much different from the results obtained by large input/output models. The size of the model does not improve its being true to the reality. Increasing the size of the model could be counter-productive by reducing the transparency of representation (i.e., obscuring what is really happening). This is particularly true when analysis is to result in real-life policies. As Manne and Richels[11] observed: *"Results should not be trusted unless they are intuitively understandable."*

Complexity is a concept (or term) which does not have a meaning in itself but acquires its meaning only in a broader context. There is a dynamic, burgeoning, exciting new field of "complexitology" which attempts to come to grips with a general theory[15]. The research has been criticized as accommodating too many distinct, even contradictory, views. This is a bit unfair because complexity is a derived rather than a primary concept. It can legitimately be defined in different ways within different contexts.

15. *M. Gell-mann,* The Quark and the Jaguar: Adventures in the Simple and the Complex, *New York, W. H. Freeman, 1994.*

Global change is most certainly a complex phenomenon. Understanding global change requires the notion of a complex system. In this regard, the notion of a complex system in the mathematical theory of general systems is relevant[4]. The starting point is the notion of a *system as a relation among items or objects. A complex system is then defined as a relation among the systems.* Items which form a complex system through interaction (i.e., subsystems) have their own recognizable boundary and existence while their behavior (functioning) is conditioned by their being integrated in the overall system. The human body is an obvious example; its parts (i.e., organs) are recognizable as such but their functioning (and even existence) is conditioned as being part of the total system, i.e., body.

In our view, it is futile to argue whether this concept is a valid representation of the complexity. What is important is whether the concept can help us in addressing the challenges such as global change. We argue that the concept of a complex system can be useful in that respect in two ways:

- in presenting a more truthful and credible representation of the global change phenomenon; and

- in providing a framework (as illustrated by multilevel modeling) for representation of the decisionmaking processes in the global change.

Several additional remarks on complexity as reflected in the above notion of complex systems can help clarify the concept:

- Complexity should not be confused with unpredictability or indeterminacy ("surprising behavior"). A simple system in the sense of being faithfully described by a small set of equations can be chaotic (i.e., indeterminate) or self-organizing (i.e., have several modes of behavior) exhibiting surprising (unexpected) behavior without being complex.

- The concept of a complex system has an intimate relationship with the concept of hierarchy (another concept which can have alternative legitimate interpretations!). The behavior of a complex system, by definition, can be considered on at least two levels:
- the level of subsystems; and
- the level of the overall system. Conversely, a hierarchical system which has two or more levels can be legitimately considered as complex.

- The distinction between complex and "complicated" systems is suggestive in this context. Paul Hindemith's music has been described as *"complex without becoming complicated, that its harmony is intricate and not involved is about as close as you can come in so brief a space to the mystical style of Paul Hindemith"*[16]. A single level, large, integrated model is "complicated". For example, some computer-based policy models takes hours, if not days, for a single run[17]. Such models are not practical for policy analysis where uncertaintly prevails and transparency is a prerequisite.

16. P. Laki, Cleveland Orchestra Annotations, 1994-95 Season, quoting George Henry Lovett Smith.

17. IMAGE 2.0: Integrated Modeling of Global Climate Change, *Joseph Alcamo, ed., Kluwer Academic Publishers, 1994.*

In its crudest form a complex system is viewed as having a large number of variables (items) and being characterized by the phrase, *"everything depends on everything else."* However, complex systems do function in nature in an orderly fashion and have so functioned throughout human history. The Roman Empire provides an example of a system that was truly complex in view of the available means for communication and management. Yet the system functioned successfully for centuries. The statement "everything depends on everything else" indicates the break-down state of the complex system which otherwise functions by its own internal management rules. Under normal conditions a complex system possesses internal rules of management or behavior which allocate the responsibilities to subsystems commensurate to information processing and decisionmaking capacities.

Multilevel modeling also provides a basis for time effective management and credible policy development in complex situations. In addition to the conceptual hierarchy illustrated in Figure 6, a hierarchy for the policy analysis is used for this pur-pose. Such a hierarchy for the problem of global coordination of national greenhouse gases mitigation policies (as used at the UNESCO workshops described subsequently) is shown in Figure 7. On the policy level, national emission targets are determined for an assumed coordination mechanism (trade in carbon rights, mitigation fund, etc.) using aggregated indicators (e.g., per unit cost of emission reduction as a function of time and volume).

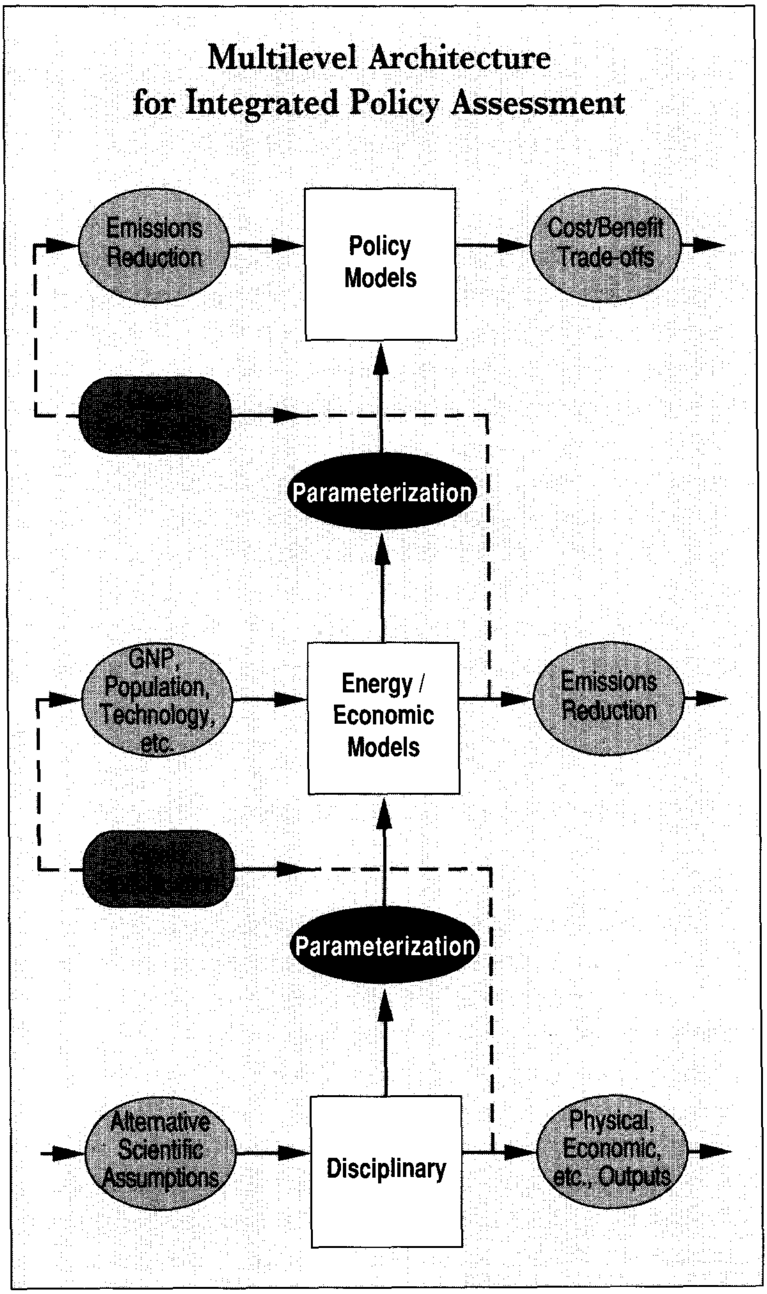


Figure 7

The emission targets are then used on a more detailed level (referred to as the *system* level) to identify feasible conditions to meet trade-offs on the policy level. For example, a degree of reduction of energy intensity (conservation, change in energy mix from fossil fuels to other sources, etc.) On the disciplinary models level the feasibility of these changes are evaluated. Models on higher levels are parameterized by the information from the more detailed, lower level models.

The analysis using the hierarchy of models can also be conducted from the bottom-up. Changes are assumed on the lower levels and the impact on trade-offs is evaluated on the policy level.

- The multilevel approach to complexity should be contrasted with single discipline models. In the latter, phenomena from other disciplines are considered as externalities by translating the concepts (variables) from other disciplines in terms of the concepts of the main discipline. Systems dynamics which restrict attention to time changes is another example of "flattening" real-life hierarchy.

- The scale at which the policymakers function is different from the level of policy analysis using integrated models. Von Storch[8] suggests the scale difference between global climate models and the need for analyses related to human scale activity is a primary problem in global change studies. The development using the hierarchical architecture of the ensemble of models helps in facing this dilemma.

5 Integrated Assessment as a Process

Integrated modeling for climate change was heralded as meeting the need to consider several scientific disciplines at the same time. The initial euphoria about integrated modeling had to be tampered with because the futures outlined by different integrated models (most developed with high professional standards) turned out to be vastly different. The concept of integrated assessment is then introduced in recognition of the less than reliable forecast capabilities of such models. Although, in general, integrated assessment is not identified with integrated modeling, in practice, integrated assessment very often turns out to be the *development of an integrated model followed by sensitivity analysis.*

The reasons for the shortcomings of such an approach become apparent by taking the cybernetic view outlined above, in particular:

- Heroic assumptions have to be made for the values of the parameters in input/output (state transition) type models which result from the human (individual and social) choices. For example, the rate of change of the autonomous energy efficiency improvements (AEEI) for all regions in the world are sometimes assumed to converge and become identical from the year 2050 and beyond. Preferences, choices, and means available to societies in North America, China, Africa and Latin America are vastly different, and they can hardly be expected to converge in such a relatively short interval or even in the longer foreseeable future. Attempts can be made to remedy this by extensive sensitivity analysis, but the range for such analysis again cannot be meaningfully identified without paying attention to the underlying social processes, individual preferences, values, and the likes.

- Because of the certainty (determinism) introduced by integrated models, the results of analyses using these models are being questioned. For example, the National Academy expresses a preference for the "bottom-up" engineering approach as contrasted with the "top-down" integrated modeling approach[18].

- Decisionmakers face a multiplicity of conflicting objectives - mitigation of climate change being only one of them. Analysis of the conflict between developmental and climate change mitigation objectives by Goldemberg[19] points out the potential unsustainability intrinsic in global climate change mitigation. Sustainable development has been widely accepted as a paradigm for a desirable future. In the assessment of conditions for sustainable development, the emphasis has been put overwhelmingly on resources and the supporting environment. Although the social and human domain of the world problematique has been recognized, it has not been accounted for in the analysis. Yet without sustainable societies there cannot be sustainable development. After all, sine qua non of development is the satisfaction of basic needs: physical, societal and psychological. A sustainable society requires satisfaction of basic human needs, which in turn requires energy available at the location, which contributes to greenhouse gases concentration and impacts sustainability of development (Fig. 8).

18. Policy Implications of Greenhouse Warming - Synthesis, *Panel Report of National Academy of Sciences, National Academy Press, Washington, DC, 1992.*

19. Jose Goldemberg, Energy Needs in Developing Countries and Sustainability, Science, *Vol. 269, August 25, 1995, pp. 1058-1059.*

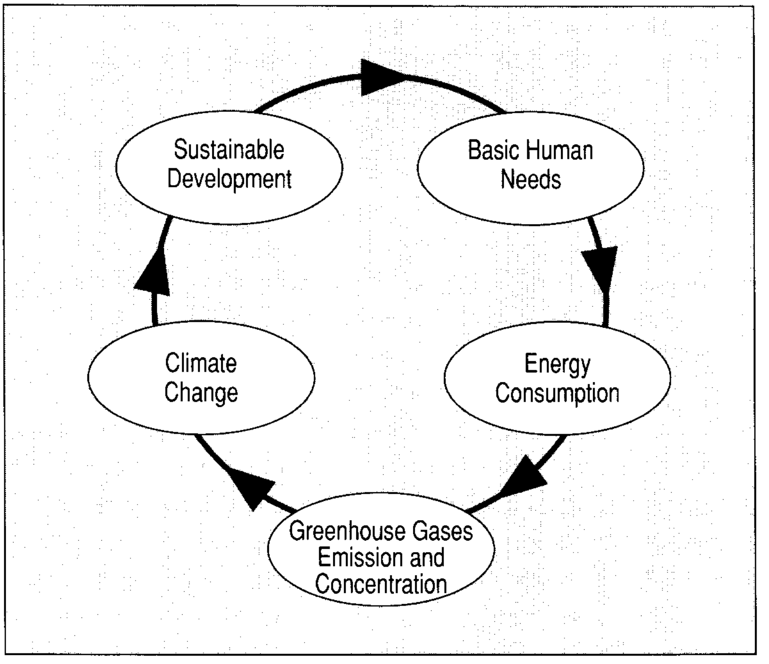


Figure 8

Satisfying the basic human needs objective and the objective of sustainable resources use and environment are in conflict. Focusing on one of these two objectives while ignoring (openly or implicitly) the other objective is a non-starter. There is hardly a need for complex analysis to appreciate the reality of the conflict between these two objectives. Consider the case of China. China consumes at least 25% more coal than the United States while using ten times more energy per unit of GNP. Even at a moderate economic growth rate (e.g., assumed by the IPCC) the use of coal in China will triple by the middle of the next century. If a higher (at present, more probable) growth rate for China is assumed the coal consumption will be even higher. It is to be expected that China will make efforts, on her own and with the help of the international community, to reduce environmental degradation, but it is hard to envision how the use of fossil fuels in China can be reduced to the extent needed to keep the emission of greenhouse gases near the required 1990 level as indicated for the amelioration of the global warming prospects.

Identifying realistic policy alternatives cannot be solved by computer models alone. While computer simulations may provide useful information and guidance, decisionmakers are faced with a more complex process in creating effective policies.

Simulation models in a prediction mode must be taken for what they are, one version of the future based on a set of algorithms within computer software. To represent realistically the role of the human, it is necessary to change decisions and algorithms during the very process of the scenario evolution in simulation time to reflect changing conditions and allow stakeholders to seek specific goals, not all of them representable in numerical form. An alternative to using integrated modeling is to use partial, more credible models (or even trends) and support reasoning about the future by explicit argumentation about the logic which leads to the statements about the future.

A good example is the limits to growth dilemma. Arguments in favor of limits to growth are much more convincing by the analysis in separate scientific domains and interpreting the results, rather than by arguing that the limits are proven by a "Newtonian mechanics" construction (model). The prospects for doubling Africa's population in one or two generations and the analysis of the carrying capacity of the African continent conducted by IIASA and the FAO[20] (which concluded that the carrying capacity in a number of African countries will be exceeded early in the 21st century) clearly indicate that the limits to growth requires serious considerations. This is why arguments in favor of limits based on partial but credible evidence, e.g., Daly[21], carry more weight than the arguments based on simple (or complex) models with questionable relationships. Similarly, the analysis by Cline[22] of the climate change mitigation appears more convincing than model-based analysis, such as, e.g., based on optimal behavior of humans and societies[23]. Even if the assumption about the optimal path development (economic, energy, technology, etc.) in the highly industrialized countries such as the U.S. and Germany is accepted (a big if), it is hard to discern optimal behavior, not only in countries such as Zaire and Somalia, but even in Brazil and India.

From the cybernetic viewpoint, integrated assessment is a human-based process of reasoning about the future in which all available tools and information are used in contrast to the *computer-based approach,* such as in integrated modeling plus sensitivity analysis. The process is akin to the decision support approach used in management science and practice.

20. Carrying Capacity of African Countries, *IIASA/FAO, Laxemburg, Austria, 1990.*

21. H. Daly and J. Cobb, For the Common Good, *Boston, Mass., Beacon Press, 1994.*

22. W. Cline, The Economics of Global Warming, *(Institute of International Economics, Washington, DC, USA, 1992).*

23. W.D. Nordhaus, Managing the Global Commons: The Economics of the Greenhouse Effect, *Cambridge, MA, MIT Press, USA, 1994.*

6 GLOBESIGHT - A Case Study

To research integrated assessment as a process, a *prototype* of an integrated assessment support system (named GLOBESIGHT - from GLOBal forESIGHT) has been developed and used in several alternative circumstances. It belongs to the class of active decision support systems investigated by Yasuhiko Takahara[24]. In the process of reasoning about the future GLOBESIGHT plays the role of a "consultant." Historical data (time series), other kinds of information (i.e., textual), and a family of models (both integrated and partial) are used in the reasoning process. The architecture of GLOBESIGHT is shown in Fig. 11.

24. *Yasuhiko Takahara, et. al.,* A Hierarchy of Decision Making Concepts - Conceptual Foundation of DSS, *J. of General Systems Theory, 1994.*

The *Information* Base contains numerical time series, textual information, etc. which the user can consult when formulating policies and assumptions.

The *Models* (Algorithms) *Base* contains a plethora of procedures to explore feasible future evolution and consequences of policies.

The *Tools Base* contains interactive procedures which allow the user to actively participate in the process.

The *Issues Base* is a depository of the analyses (results, as well as assumptions) already conducted for future reference, comparative evaluation and extension of analyses.
Using a time interactive, "reflexive", feedback configuration of the human and the computer (as illustrated in Fig. 9), the human and the computer "walk hand in hand", step by step, along alternative, feasible, future paths. The time horizon is broken into shorter time intervals and at the end of each time interval the human reconsiders assumptions (regarding policies, as well as scientific uncertainties) and makes the necessary changes for the next time interval. *The scenario which emerges in such a process is not known beforehand* (i.e., at the beginning of the model run). It is the result of a symbiotic relationship between the human and the computer in which objective (numerical) and subjective (human visions) sides of the future evolution are blended.

The integrated assessment process approach is being used in two ongoing efforts:

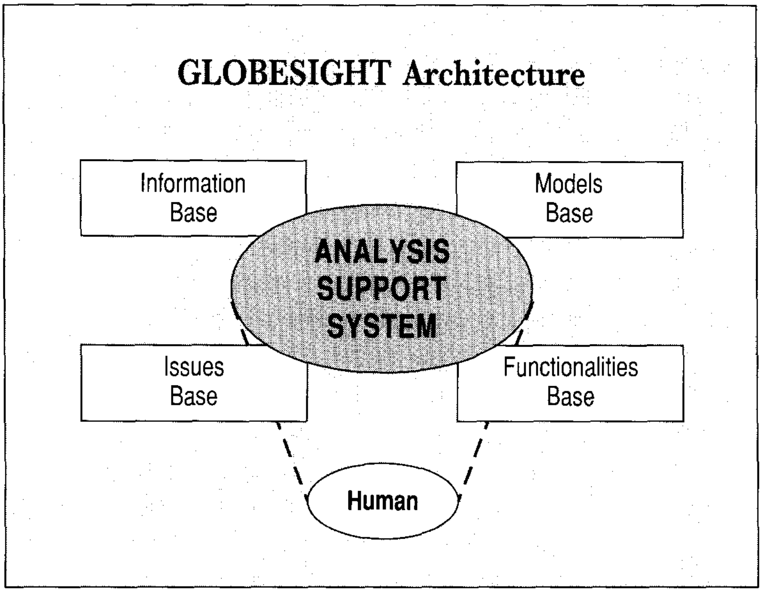


Figure 9

■ A series of UNESCO workshops on Bridging the Gap Between Science and Decisionmaking·

Two workshops have been held so far: the first was held in May of 1993 in Venice, Italy; the second in September of 1994 in Santiago, Chile. The second workshop focused on the Western Hemisphere and was co-sponsored by the Inter-American Institute for Global Climate Change Research (IAI). Twenty-six nations and international organizations participated in the workshops[25]. Each nation's/organization's team consisted of at least one scientist and one decisionmaker. The advantages of using the integrated assessment process in international negotiations and national/international consensus building was one of the focal points of the proceedings. Feasibility of a joint and integrated effort of science/policy communities for better utilization of science by decisionmakers and the ability to identify priorities for future scientific research more responsive to decisionmakers needs were also considered.

25. List of countries and organizations that participated in the UNESCO Workshop held in Venice, Italy, in May, 1993: Brazil, China, Egypt, India, Italy, Mexico, Russia, USA, European Community, UNEP, UNDP, WMO, University of Venice, Municipality of Venice, Third World Academy of Sciences, Association for Global Studies, UNESCO.
List of countries and organizations that participated in the UNESCO Workshop held in Santiago, Chile, in September, 1994: Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Mexico, Panama, Paraguay, Peru, Uruguay, USA, IAI, UNESCO.

The workshops involve scientists and decisionmakers (or their staff) in a joint effort of policy development in which both sides are active participants. Using GLOBESIGHT and proceeding step-wise in time intervals, assumptions on policies and uncertainties (scientific and other) were formulated in a dialogue involving both sides. The workshops started with background scenarios and some policy scenarios based on publicly available information[26]. Participants were then involved in developing their own scenarios by modifying assumed policies in a time interactive process to conform to their own views. At the Venice workshop, the background scenarios were changed by the participants, particularly in reference to the nuclear option for the European Community and the energy conservation and change in energy mix in China. At the Santiago workshop questions were raised of specific interest to Latin America and corresponding scenarios were developed in a "game-like" and step-wise iterative process with active involvement by all participants. Questions raised by the participants at the workshop and analyzed in the participatory effort included the following:

26. *A. Ilyutovich, B. Venkatesh, N. Sreenath and M. Mesarovic, Multi-level Architecture for Integrated Assessment of Global Climate Change Mitigation Policies,* Int. J. of General Systems, 1996.

- How important is Latin American participation in the global effort to reach the global emissions reduction goal by the reduction of fossil fuel use, and what would be the impact of such policies on regional development prospects?

- Deforestation is clearly of major concern for bio-diversity. However, how important is the reduction of deforestation to the climate problem?

The results of the scenario exercise are illustrated in Figs. 10-14.

In the Business as Usual scenario (no action!), the Latin American percentage of global emission contribution declines at the year 2030 from 11% to 10% (Figs. 10 and 11) of the world emission. With *full participation* of Latin America in the global cooperation case the Latin American contribution declines at 2030 to 8% rather than 10% (Fig. 12). The reduction in energy use in the case of full compliance of Latin America with the Rio treaty, measured in energy intensity (energy consumption per unit of GNP), is shown in Fig. 13. Energy consumption per GNP has to be reduced to one-half compared with the BaU case. The impact of energy shortage and investment needed for industrial development in such a case were considered to be far in excess

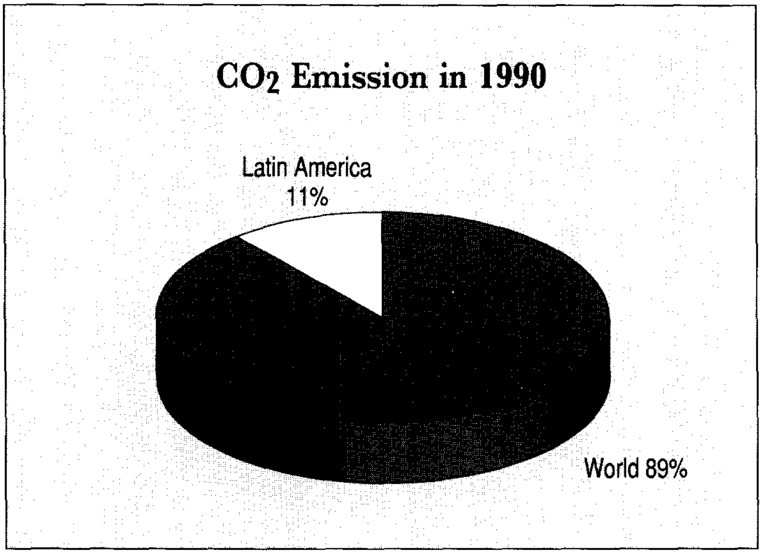


Figure 10

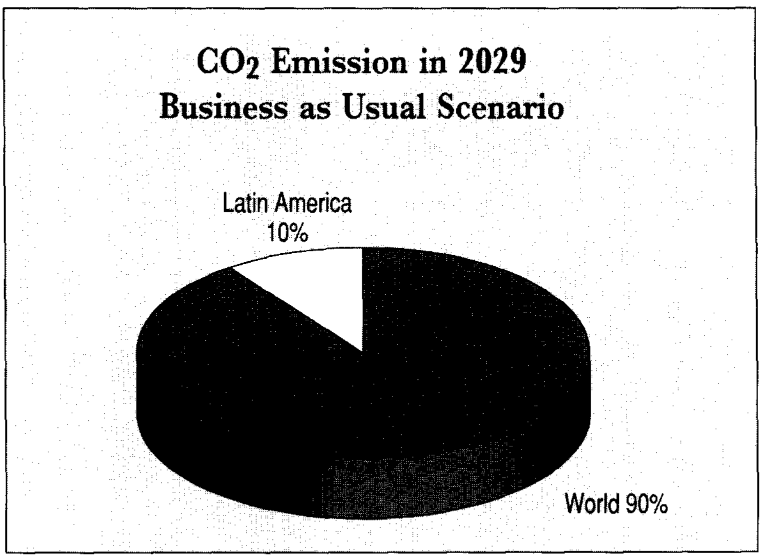


Figure 11

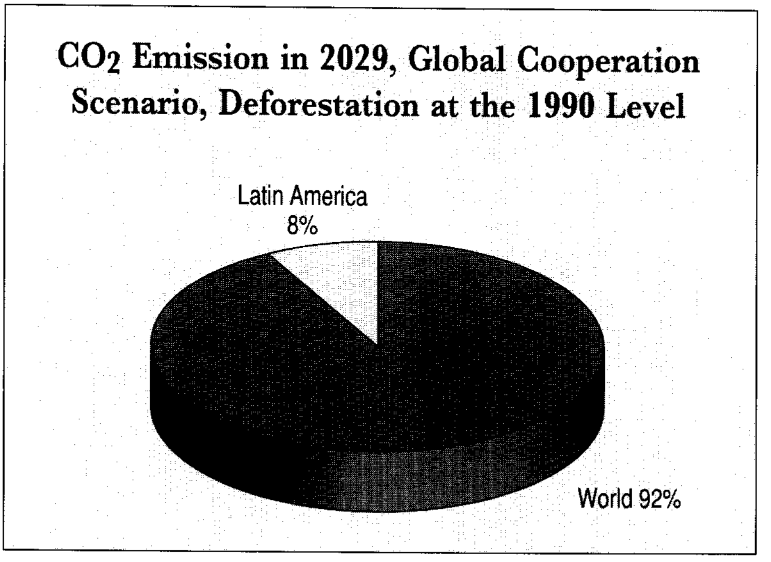


Figure 12

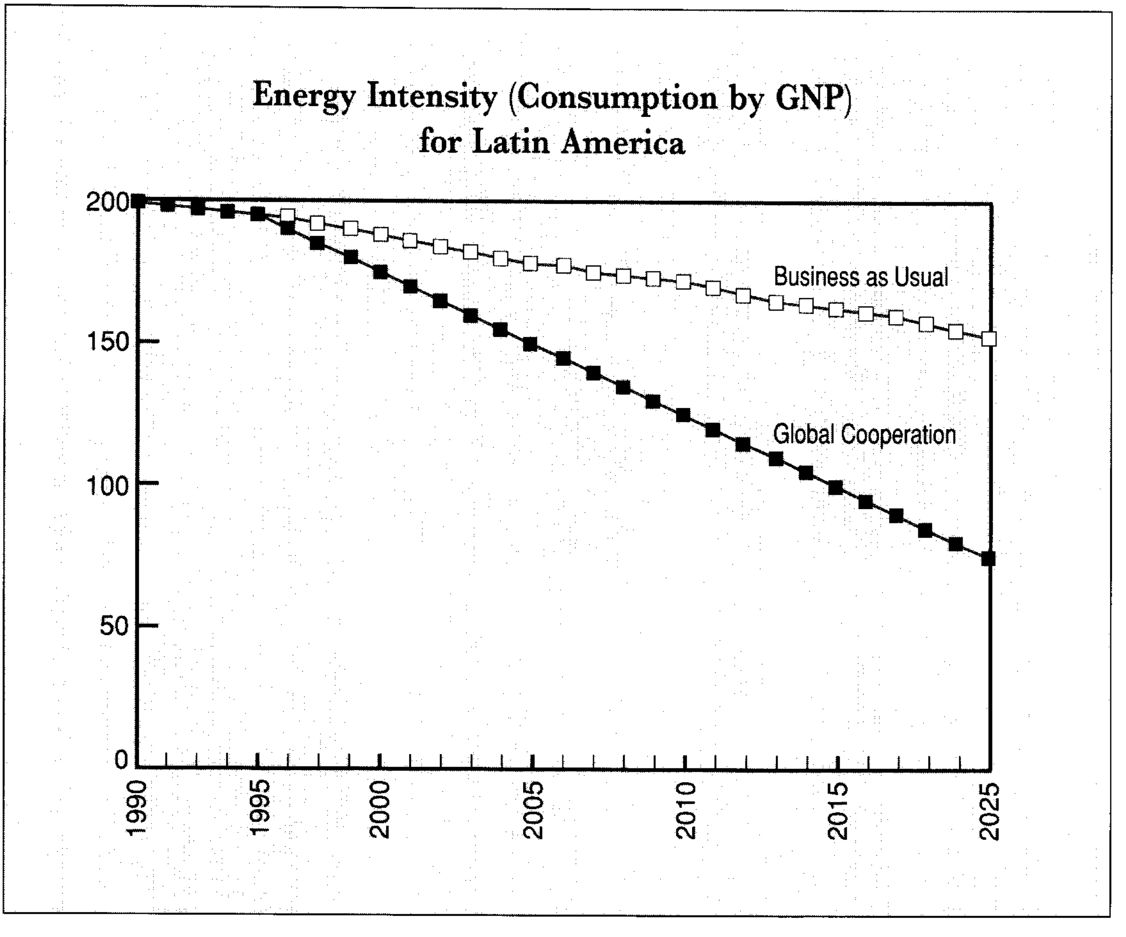


Figure 13

of contribution to the global goal which amounts to barely 2% (8% rather than 10%) of the world impact. In view of the relative marginal impact of the Latin American effort and with recognition of the uncertainties involved, opinions were expressed that Latin American abstention in the global effort can be rationalized and that other regions which will be much higher polluters by the year 2030 have to carry the burden.

A similar conclusion was reached in reference to the importance of deforestation for climate change. A scenario was developed at the workshop in which deforestation in Latin America was reduced gradually to zero by the year 2030. A rather extreme assumption! The Latin American contribution (all other assumptions being the same) reduces from 8% to 6% (Fig. 14). Still a marginal impact on the global effort.

The impact of Canadian participation in emission reduction versus an adaptation strategy were also considered. Because of its geographic position and an expected milder climate in Canada resulting in the extension of the growing season for agricultural products, it was argued that the adaptation strategy, rather than mitigation (emission reduction), was preferable for Canada.

Both of these conclusions lead to the global commons dilemma: if all regions follow their preferable course of action the global goal will not be achieved by default. The conclusion from the proceedings, then, was that if the global goal is to be achieved, the policies cannot be based on an independent, separate assessment of local conditions but have to be negotiated using scientific facts (for the sake of credibility) and with all sides involved on an equal footing (for the sake of acceptability of conclusions). Hence, the need for a participatory, consensus-building, negotiation support process which blends scientific knowledge with developmental objectives.

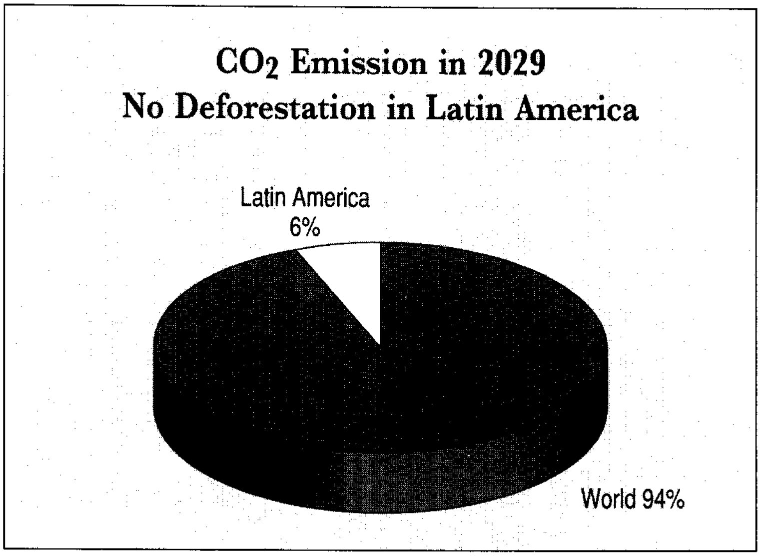


Figure 14

2 Education for the 21st Century.

The need for a new pedagogy to prepare youth for the challenges of the global society in the 21st century is widely recognized and debated. In addition to strengthening education on traditional subjects, the need to provide the students with critical thinking and problem-solving skills by what is called "active learning" has been emphasized. Global change provides an appropriate topic for such a new pedagogy. The approach has been used in university-wide undergraduate courses at Case Western Reserve University for more than five years and will be offered in an appropriately modified form to two high schools in Ohio. A preliminary evaluation by teachers and students in Ontario, Canada, has been very encouraging.

UNESCO has launched a Globally-Oriented Universities Education Consortium with the goal of establishing a network of universities in selected parts of the world whose students will be engaged in the examination of conditions for sustainable development and social harmony. The participants will be connected via the Internet and will share data and textual information bases, models and assessment algorithms, etc.

The pedagogical principles for the effort include:

- A holistic view of global change based on a multi-disciplinary foundation;

- The blending of physical and social sciences with the humanities (scientific facts and knowledge with humanistic goals and visions).

- The use of advances in informatics to enable the students to manage the complexity of the world problematique and address a plethora of uncertainties intrinsic in the integrated assessment of alternative global futures.

- Provide a channel for students from different cultural backgrounds and who face different sets of issues to communicate, sharing their experiences and promote understanding.

The initial members of the Consortium are Case Western Reserve University (Cleveland, Ohio, USA), Bilkent University (Ankara, Turkey) and the Technical University of Catalunya (Spain). Up to twelve other universities from different world regions are being invited to participate in the first phase of the program. The project, is developped within the context of UNESCO's Management of Social Transformation Programme (MOST), UNITWIN-UNESCO Chairs Programme, as well as Coordination Unit for the Environmental Programmes.

7 Domain of GLOBESIGHT Applications

GLOBESIGHT is just a prototype of a tool which will enable development of rational, fact-based, integrated assessment as a process. The potential applications of such an approach include:

1 Multi-agency cooperative development of policies.

The policymaking and the science of climate change operate separately ("at a distance") guided and constrained by their own distinct values, criteria, methodologies and processes. Science generates knowledge and facts, policymaking is motivated by values and objectives. Typically, the interaction between the two communities takes place in one of two ways:

- science discovers some facts which have policy implications and calls possible implication of the new knowledge to the policy-makers' (and the public-at-large) attention;

- policymakers face a dilemma which can be addressed more satisfactorily if scientific research can provide answers to certain questions. Scientific research is then conducted providing the answers to the extent that data and knowledge are available at the time.

The prevailing way of science/decisionmaking interaction is that the two activities proceed in parallel with "contacts" at appropriate points in time; e.g., when the policy related questions are raised and when the scientific research answering these questions is completed. Scientists produce reports which are then explained and summarized for use in decisionmaking. The use of a GLOBESIGHT-type support system has two advantages:

- it would involve decisionmaking bodies as participating partners in actual policy development; and

- it would facilitate identification of the scientific research priorities more directly responsive to policy needs.

A facility can be developed based on the GLOBESIGHT concept for participation of different agencies in the process of policy development, from the diplomatic and policy perspective to science, technology and data perspectives.

2 Support in international negotiations and consensus building.

International negotiations are conducted in the political arena with diplomatic concerns often playing a dominant role. The Earth Summit held in 1992 in Rio de Janeiro and negotiations which preceded it are no exceptions. While information provided by science is being considered in such fora in a general way, the negotiation process can be expedited and focused more sharply on the specific points of contention if the reasons for different positions of negotiations are better understood. An integrated assessment negotiation support system can contribute significantly to such a process. An illustration of the use of the system for support in decisionmaking and negotiations is provided by the UNESCO series of workshops mentioned earlier.

3 Presentation to the public (non-expert) audience of the policy impact and potential benefit from the results of scientific research.

The support system can be used on-line to respond to the questions from the audience as to the reasons for the selection of the proposed policy, success of the policy under changed circumstances, consequences of alternative policies, and the likes.

4 Networking of researchers

for sharing information, avoiding duplications, etc. Climate change research is being conducted by a vast number of researchers around the world. Sharing of information and communication about the results, objectives, plans, schedules, etc., of research could greatly enhance the cost effectiveness of the future global effort and expedite the progress. The Information and Models Bases of a GLOBESIGHT-type system implemented on Internet for use world-wide would enhance collaboration between scientists.

5 Education and training

in a formal setting such as in universities, high schools, and briefings for decisionmakers and their staff, etc.

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