4. METHODOLOGY: TOWARDS INTEGRATED ASSESSMENTS WITH REASONING SUPPORT TOOLS

4.1. CHARACTERISTICS OF GLOBAL EARTH/HUMAN ISSUES AND SYSTEMS: UNCERTAINTY AND THE GOAL-SEEKING (OR DECISION-MAKING) PARADIGM

4.2. CHARACTERISTICS OF GLOBAL EARTH/HUMAN ISSUES AND SYSTEMS: COMPLEXITY AND MULTILEVEL HIERARCHY MODELING

4.3. CHARACTERISTICS OF GLOBAL EARTH/HUMAN ISSUES AND SYSTEMS: MULTIDISCIPLINARY AND MULTILEVEL VERSUS INTEGRATED MODELING
4.3.1. DECONSTRUCTION OF A SYSTEM AND HIERARCHICAL REPRESENTATION

4.4. INTEGRATED ASSESSMENT AS A PROCESS

4.5. GLOBESIGHT: A REASONING SUPPORT TOOL

4.6. THE MODELS BASE IN GLOBESIGHT
4.6.1. ABOUT THE MORE GENERAL EQUATIONS IN OUR GLOBESIGHT MODELS

4.7. SCENARIO ANALYSIS

4. METHODOLOGY: TOWARDS INTEGRATED ASSESSMENTS WITH REASONING SUPPORT TOOLS [B.7.]

4.1. CHARACTERISTICS OF GLOBAL EARTH/HUMAN ISSUES AND SYSTEMS: UNCERTAINTY AND THE GOAL-SEEKING (OR DECISION-MAKIND) PARADIGM

The global earth/human issues and systems are characterized by both complexity and uncertainty. Often these characteristics are confused with one another. For instance, a simple system defined by a single equation could be highly uncertain. On the other hand, a complex system could be completely certain.

These issues and systems are full of uncertainties and risks, they are transnational in nature; they have long range impacts covering multiple generations; they concern many people on our planet; they are related to human behavior (consumption, mobility, technology, demography, etc.) but they have also its indigenous development; they are connected with almost all economic activities; etc.. Clearly a number of fundamental characteristics of this issues and systems lies in the organization and function of society itself, so that a thorough analysis of decision-making mechanisms is a sine qua non. In this framework, sufficient attention to decision risks, in connection with basic uncertainties inherent in social research, related with environmental problematique is necessary.

In fact the main characteristic of theses issues and systems is customarily described in terms of the so-called human dimension, human factor, 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., change in agricultural productivity under assumed change in the atmosphere, etc..

And so the key question 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. **This requires: 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.

The first aspect (the relationship of humankind with nature) is best understood in terms of the reflexivity concept (see Figure 4.1.). 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 environmental 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). 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 earth/human systems is central to understanding the human role in global environmental change.

Figure 4.1.:
Reflexive relationship between humankind and nature
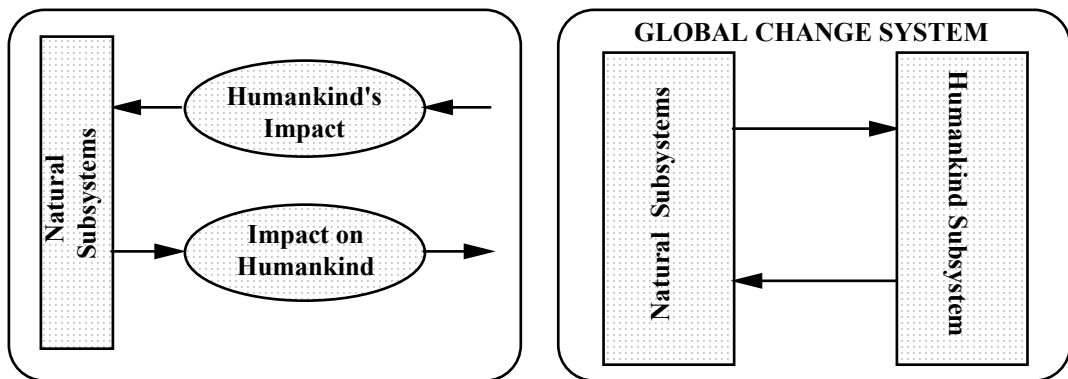
The second aspect (proper representation of the specific character of humankind and the role it plays in global environmental change) needs a paradigm different than the input/output or state transition paradigm used thus far in the study of global change. In the state transition paradigm the system 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 wide from 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 decisionmaking) paradigm. It has its origin in biology and the study of human behavior rather than 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 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), available to the system in response to what is happening or is expected to happen in the system's environment.

- A range of uncertainties, 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 due to 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.

- An evaluation set ("performance scale"), 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) the system expects after a decision is implemented and the environmental influence is correctly anticipated. In reality, it is seldom, if ever, a complete and accurate reflection of the reality.

- An evaluation mapping, used to compare the outcomes of the decisions using the preference scale, and taking into account the "extent or cost of the effort".

- The tolerance function (relation) which indicates the degree of satisfaction with the outcome if a given uncertainty comes to pass. 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 the performance of the system can be allowed to deteriorate for some uncertainty, but it must stay within a tolerance limit which will ensure "survival of the system".

This paradigm accommodates concepts of "satisfactory human behavior" as opposed to the "optimization" view commonly used in economic theory, explicitly accounts for uncertainty - both true uncertainty and uncertainty under risk (usually accounted using probability theory), and tolerance (acceptability, survival, etc.).

An important role in this formulation is explicit recognition of uncertainty and the concept of tolerance (acceptability, survival). The performance can deteriorate for extreme occurrences 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 occurrences.

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 programs for theorem proving, chess playing and the likes. These programs 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 has recently observed *"...the very notion of what constitutes 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."*

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

- 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.

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. 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-. A brief description of such an interaction in reference to time evolution is given in the Figures 4.2 and 4.3.

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 is used in this studies. In traditional scenario analysis (Figure 4.2.) 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.

In the interactive process used in the police analysis (Figure 4.3.) 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 program portion of the model generates

Figure 4.2.

Scenario Generation Using the
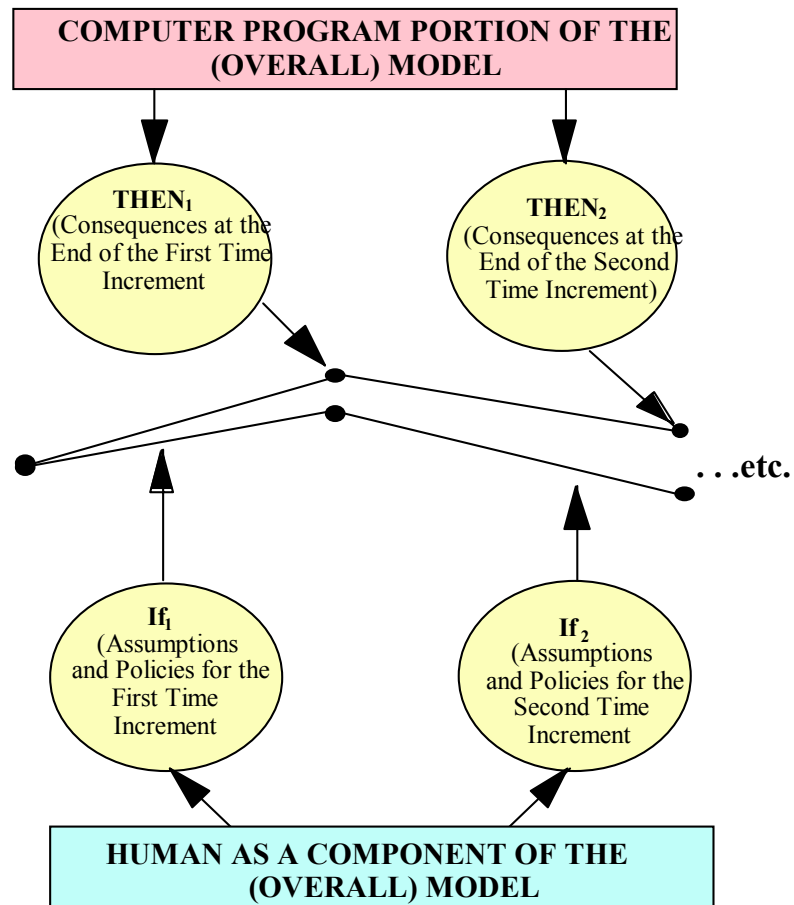**Traditional Computer Modeling Approach**
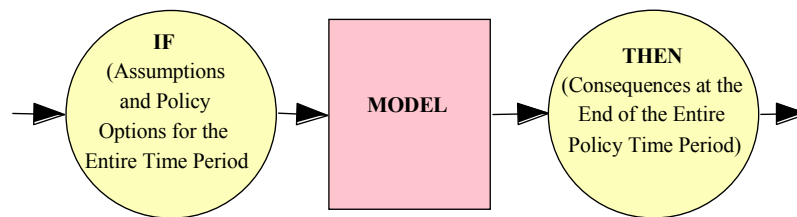
feasible consequences of the policies and assumptions at the end of the first increment. The human then makes new policy choices and assumptions for the second time increment on the basis of the newly arrived at state of the system at the end of the first time increment. In response, the computer generates 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).

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 and common sense, vision, views on uncertainty, etc., (subjective aspects) are needed from where the logic, numbers, and facts (objective aspects) are used for deeper computer analyses. 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.

Figure 4.3.

Scenario Generation Using the
Human/Computer Partnership Process

COMPUTER PROGRAM PORTION OF THE (OVERALL) MODEL

$THEN_1$ (Consequences at the End of the First Time Increment

$THEN_2$ (Consequences at the End of the Second Time Increment)

If_1 (Assumptions and Policies for the First Time Increment

If_2 (Assumptions and Policies for the Second Time Increment

. . .etc.

HUMAN AS A COMPONENT OF THE (OVERALL) MODEL

4.2. CHARACTERISTICS OF GLOBAL EARTH/HUMAN ISSUES AND SYSTEMS: COMPLEXITY AND MULTILEVEL HIERARCHY MODELING

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.

Actually, in a number of instances a simple projection of trends is not much different than 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.

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. 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.

Global environmental change is most certainly a complex phenomenon. Understanding global environmental 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. **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 environmental 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 environmental phenomenon; and   in providing a framework for representation of the decisionmaking processes in the global environmental 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. A single level, large, integrated model is "complicated". For example, some computer-based policy models takes hours, if not days, for a single run. Such models are not practical for policy analysis where uncertainty prevails and transparency is a prerequisite.

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 functioned as so 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 breakdown 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 their information processing and decisionmaking capacities.

Multilevel modeling also provides a basis for time effective management and credible policy development in complex situations. Such a hierarchy for the problem of global coordination of national greenhouse gases mitigation policies is shown in Figure 4.4.

Figure 4.4.

**Multilevel Architecture for
Integrated Policy
Assessment**
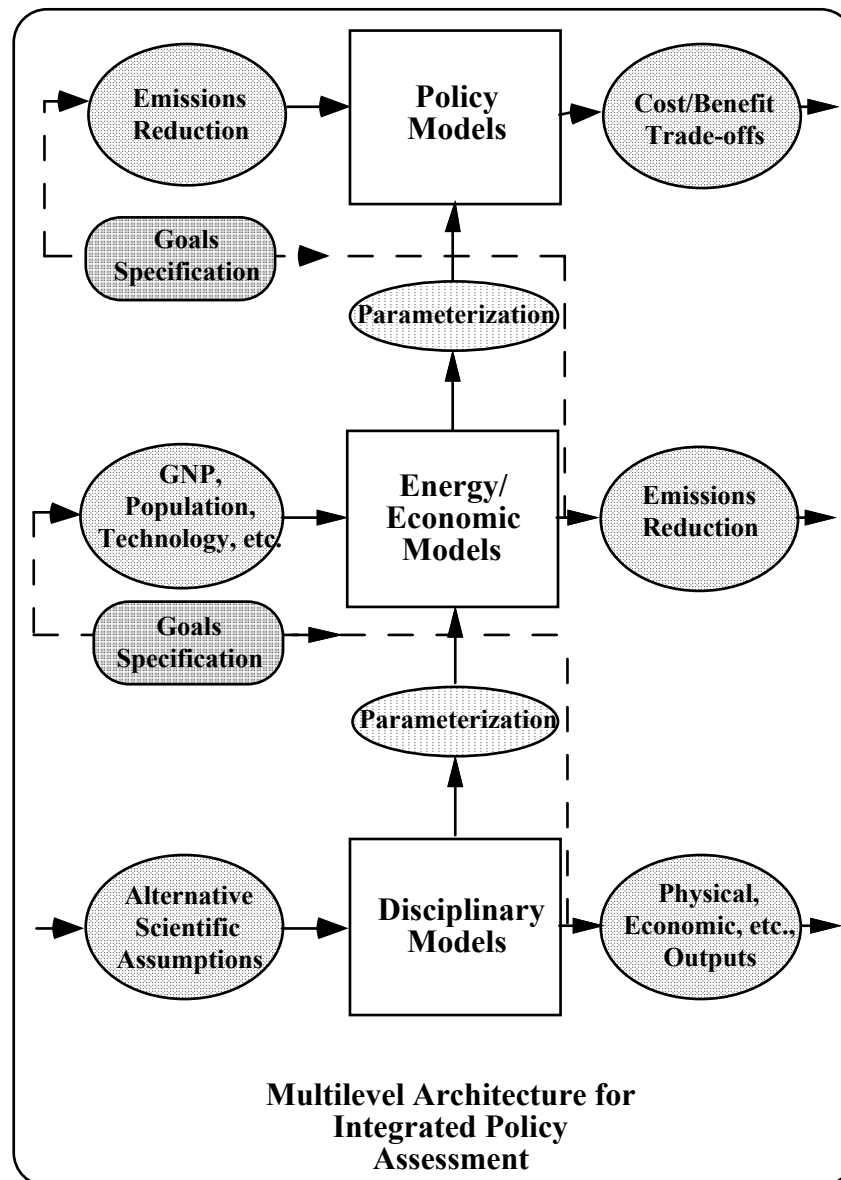
On the policy level, national emission targets are determined for an assumed
coordination mechanism (trade in carbon rights, mitigation fund, etc.) using
aggregated indicators (e.g., per unit cost of emission reduction as a function of
time and volume). The emission targets are then used on a more detailed 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 hierarchy 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 than the level of policy analysis using integrated models. The development using the hierarchical architecture of the ensemble of models helps in facing this dilemma.

4.3. CHARACTERISTICS OF GLOBAL EARTH/HUMAN ISSUES AND SYSTEMS: MULTIDISCIPLINARY AND MULTILEVEL VERSUS INTEGRATED MODELING

The need to represent phenomena from different scientific disciplines in the modeling of global earth/human issues 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 while, more recently, the emphasis has been on climate change. 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 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 than 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.

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 than observed in real life. Even a simple and weak linkage 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 to account 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 elasticity's in economic modeling to represent the outcome of exceedingly complex decision processes. A small set of numbers (values of elasticity's) 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
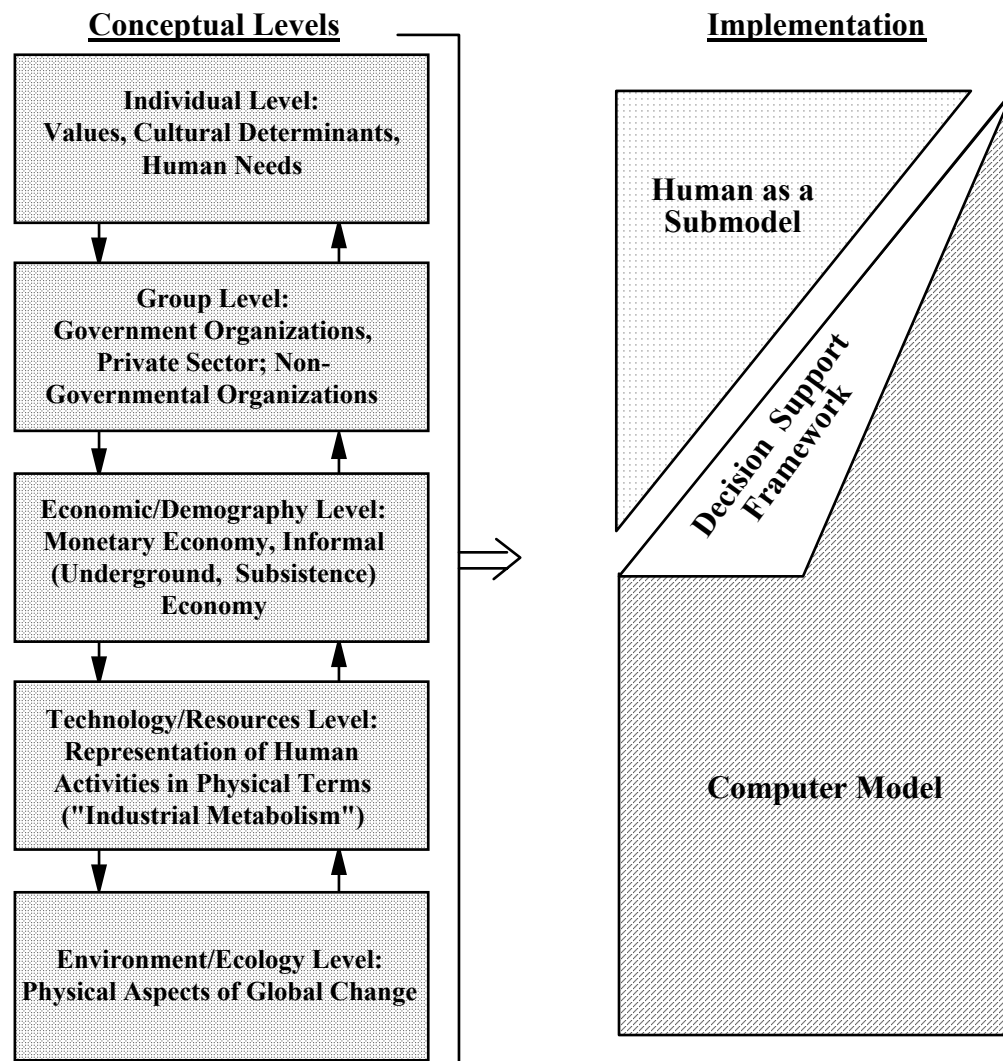
horizons depends on human decisions (individual and societal) yet to be made. Justification for relying on elasticity's to encapsulate human behavior depends on the time horizon, magnitude, rate and character of change.

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 Figure 4.5.. 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.

Figure 4.5.

Conceptual Levels   **Implementation**

```
┌─────────────────────────────┐              ┌──────────────────────────────┐
│   Individual Level:         │              │╲                             │
│ Values, Cultural Determinants,│            │ ╲    Human as a              │
│   Human Needs               │              │  ╲   Submodel                │
├─────────────────────────────┤              │   ╲                          │
│   Group Level:              │              │    ╲    Decision Support     │
│ Government Organizations,   │              │     ╲    Framework           │
│ Private Sector; Non-        │              │      ╲                       │
│ Governmental Organizations  │              │       ╲                      │
├─────────────────────────────┤     ⇒        │        ╲                     │
│ Economic/Demography Level:  │              │                              │
│ Monetary Economy, Informal  │              │                              │
│ (Underground, Subsistence)  │              │       Computer Model         │
│   Economy                   │              │                              │
├─────────────────────────────┤              │                              │
│ Technology/Resources Level: │              │                              │
│ Representation of Human     │              │                              │
│ Activities in Physical Terms│              │                              │
│ ("Industrial Metabolism")   │              │                              │
├─────────────────────────────┤              │                              │
│ Environment/Ecology Level:  │              │                              │
│ Physical Aspects of Global Change│         └──────────────────────────────┘
└─────────────────────────────┘
```

After these two last sections several remarks should be made in reference to the multilevel framework:

• The architecture shown in the last figure is only one of several possible alternatives. Important to the approach is not whether the structure shown in Figure 4.5 is the right one, but rather that a multilevel structure should be constructed as the first step in integrated modeling of complex systems.

• 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. 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.

So we can conclude that the multilevel approach helps in the management of multidisciplinary. 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.

4.3.1. DECONSTRUCTION OF A SYSTEM AND HIERARCHICAL REPRESENTATION

An example of hierarchical representation of a multidisciplinary complex system that can be deconstructed into sub-systems is given in Figure 4.6.. Starting at the top left hand corner and proceeding anti-clockwise, a gradual deconstruction process is given. A simple representation of the globe in the top left hand corner divides it into living (biosphere) and non-living sphere. Below this is the representation wherein the biosphere is further divided into non-human species sphere and non-living sphere. Together this is called Nature sphere. In the final representation in the right hand portion of Figure 4.6., the human sphere is further deconstructed into representation with hierarchies. In general the subsystems at the top in a hierarchical representation provide constraints through the downward directed arrows, whereas the upward arrows from the subsystems at the lower levels provide performance specification to their upper level. Other examples of such hierarchical stratification is given in Figure 4.7..

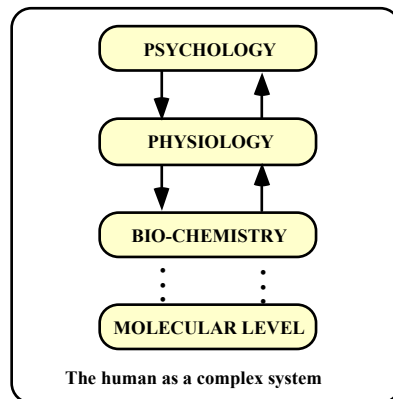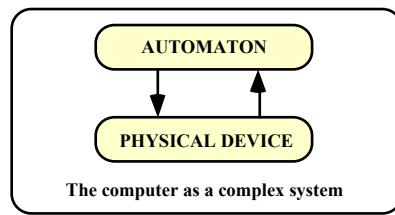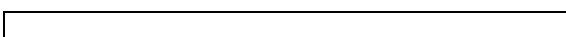### Figure 4.6.: Deconstruction of the Global System
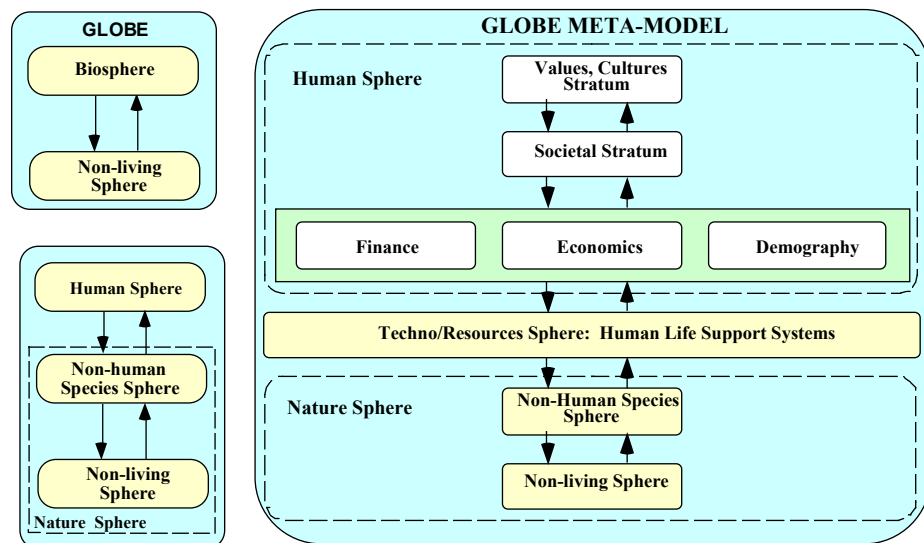
Figure 4.7.: Other examples of hierarchical representation

The computer as a complex system

The human as a complex system

Stratification Hierarchy: Conceptual Levels

A four-strata diagram of a poem reciting machine
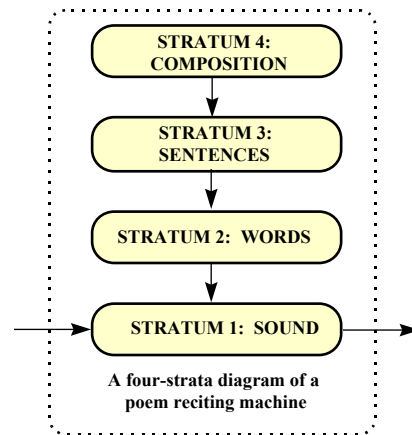
4.4. INTEGRATED ASSESSMENT AS A PROCESS

The concept of integrated assessment is then introduced in recognition of the less than reliable forecast capabilities of integrating modeling. 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.

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.

4.5. GLOBESIGHT: A REASONING SUPPORT TOOL

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 around the GENIe (Global problematique Education Network Initiative), and under the leadership of Professor Mihajlo D. Mesarovic. In the process that begin in understanding the past, evaluating the present and looking into different feasible futures, GLOBESIGHT, playing a role of a "consultant", requires the human to represent the subjective and qualitative aspects of the issue at hand whereas known data, procedures, models are inherent in it. 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 Figure 4.9.. GLOBESIGHT reasoning support software has been available on SUN hardware as well as PC hardware for a number of years. SUN Solaris and LINUX version are available. Currently only Microsoft Windows 95/98 and Windows NT are supported. The front end is based on Visual C++/Visual Basic with the back end in MS Access.

Using a time interactive, "reflexive", feedback configuration of the human and the computer, 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. (Remember the detailed discussion of section 4.1.).

So with this reasoning tool we are able to, as a summary,:

- **Blending Science with Vision:**

To quote Federico Mayor, Director General of UNESCO, in 1995: "*The challenge in bridging the gap between science and decision making is in blending reasoning with vision*". In other words we want to blend objective with subjective, quantitative with qualitative, numerical with non-numerical. This means that one needs to

account for scientific as well as political, sociological, and behavioral -the so called soft aspects- explicitly when considering modeling policy formulation and analysis.

- **Reasoning About the Future:**

Foresight and insight rather than forecast (numerical prediction), is at the heart of our approach (see Figure 4.8.). Developing foresight involves considering all possible (not probable) contingencies and developing a feel for potential futures. As one saying goes -the future is not yet determined completely since decision about the future are yet to be made. Thus, we rule out forecast as a goal. True uncertainty in parameters would not allow us to forecast. Insight, on the other hand, relates to the approach of determining or finding dominant relationships that helps in understanding and explaining away the system behavior based on experimentation of the model.

Figure 4.8.: Difference between forecast, foresight, and insight

|	
FORECAST	PREDICTION
FORESIGHT	ANTICIPATING UNCERTAINTIES
INSIGHT	UNDERSTANDING FORCES BEHIND DEVELOPMENT
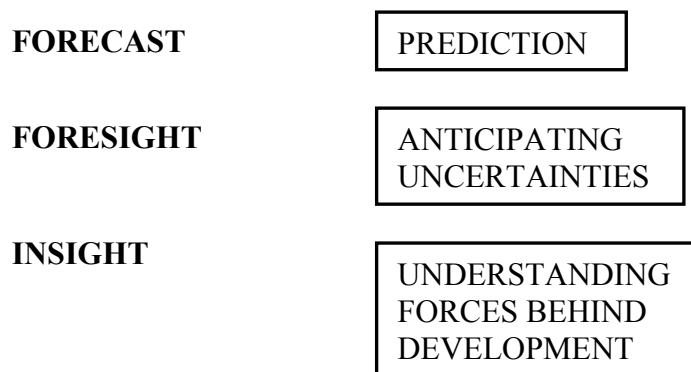
The GLOBESIGHT analysis support system consists of the following modules (see again Figure 4.9.):

- The **Information Base** contains quantitative, and verbal (or qualitative), data and information that is useful to the user for consulting during the exploration of an issue at hand. This information and data of a country/region/world takes the form of description of the geography, culture, socio-economic data and so on. The qualitative data will be helpful to the user to get a general idea about the conditions when researching specific issues in a region. The quantitative data in the form of numerical time series gives us the past and present trends in demography, economic, resources, etc..

Figure 4.9.

GLOBESIGHT Architecture
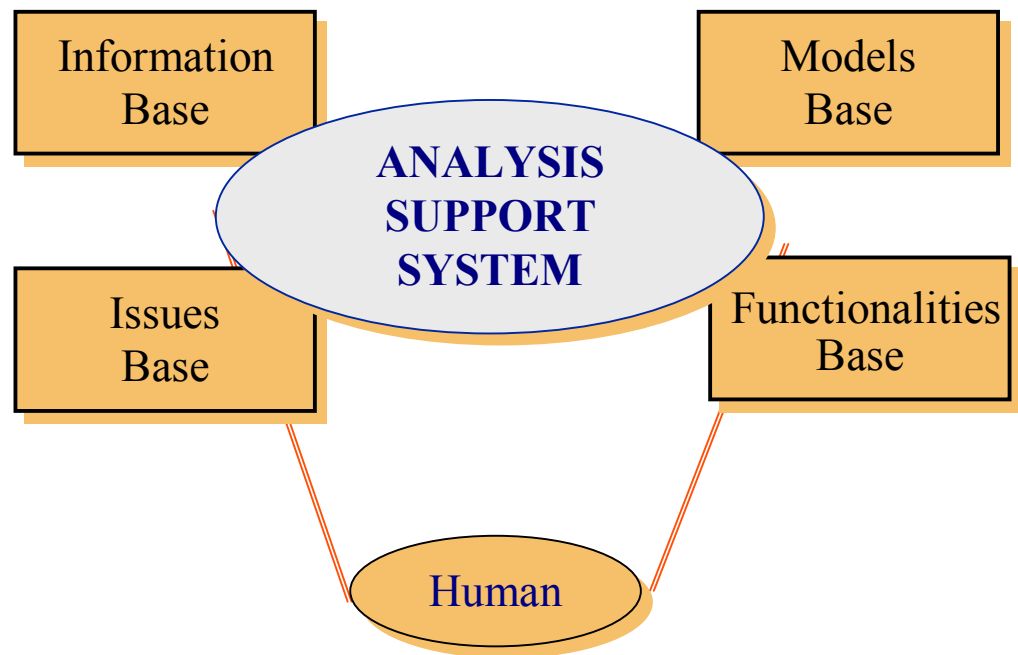
- The **Issues Base** is a depository of the analyses (results, as well as assumptions) already conducted for future reference, comparative evaluation and extension of analyses.

- The **Funcionalities Base** contains interactive procedures which allows the user to actively participate in the process. It deals with three tools basically (input, output, and process). Broadly input consists of data import and model management utilities. Utility exists to transfer data into and out of the database. Output formats include multi-axis graphs with an easy to use interface to change different type of plots (line, bar, stacked bar, pie, etc.). In addition a geographical information system (GIS) interface is available. Features such as rivers could be overlaid on the graphs. Standard geography views are included. Interpolation routine to shape key inputs such as rate of economic growth, etc. using multiple interpolation methods are available.

4.6. THE MODELS BASE IN GLOBESIGHT

First of all we try with our models to combing scientific integrity and transparency of models:

- We model only those parts of the system where scientific data and scientific knowledge is available. This essentially means "Do not model what is not modelable." Adhering to this principle is easier said than done. Modeling is an art. Knowing what aspects of the system to model and to what depth/level is primarily driven by the requirements of the analysis and the availability of data to parameterize the system. Ability to recognize this comes with experience. The models that we use are borrowed from the literature in specific disciplines, or have basis in them. Our models could be a simple representation but have to a scientific basis. Its parameters values are computed based on more complicated model runs (for example more complicated models running on supercomputer), data available through detailed analysis by credible research, and further made available in literature. In keeping with this principle we do not model the political process, expectations of the people, any behavioral aspects, values, attitudes, cultural norms, the impact of basic human physical and other needs, on society, and economy, etc. These subjective aspects accounted for by the approach labeled as "human-in-loop-with-the-computer" largely explained before.

- Models that we use will be reduced form models. This approach is one of the latest new trend in complex system modeling particularly for policy analysis (the "goal" in our study). Reduced form models also reflect the final audience for our approach who are from decision-making, education and the public domain. Rather than building complex models dominant relationships having a strong interaction between variables are identified with the parameters; complexity is traded for uncertainty in parameter changes. By reduced form models we also mean models that are easier to understand and explain to decision making staff, decision-makers or the public. This will assure that while the models are scientifically credible, the results of the models would be easy to explain. These "small" but "approximate" models are parameterized from the results of the supercomputer models. Often during rigorous scientific representation the model transparency is lost and one would require the model builder or an expert to be present to operate or use the model. This principle helps us to overcome this limitation.

Then, consequently with all the aspects seen in this chapter we try to address these considerations, as well as the need to deal with complexity and uncertainty in a proper, differentiated manner, a multilevel hierarchical architecture of integrated assessment approach is used. In the simplest terms, models for determining, for example, population evolution are developed on three levels. On the higher, policy, level, assessment is made by aggregate considerations. On that level only the key factors are represented, while detailed mechanisms of how these factors evolve over time is either assumed or delegated to separate, more specific studies. On the lower level, such detailed considerations are conducted either on an integrated or sectorial basis. The result is a two-layer hierarchical structure illustrated for the global warming issue in Figure 4.4.. The model on the higher level is parameterized by the analysis on the lower level while the results of the policy analysis on the higher level represent constraints for the assessment on the model level.

Taking population issue like another example, and the first part of the policy analysis of this study, the population model first level consists of a simple first order growth rate equation

$$pop_t = pop_{t-1} * [1 + rpop_{t-1}/100]$$

where

pop_t - population of the region in the year 't',

 and

rpop - rate of population growth in percentage

In words the equation above simply states that population next year is the population this year plus change in the population represented by the growth rate times the population this year. Such a representation is not inaccurate but could be highly uncertain with all the uncertainty embodied in the growth rate.

A second level population model resolves the uncertainty somewhat by representing the births and deaths separately but statistically through the use of crude birth (crbrt) and crude death (crdth) rate -usually given in the units of per thousands of population-. Thus the second level model is represented by:

$$pop_t = pop_{t-1} + pop_{t-1} * [crbrt_{t-1} - crdth_{t-1}]$$

and the rate of population growth is computed now as

$$\text{rpop}_{t-1} = [\text{crbrt}_{t-1} - \text{crdth}_{t-1}]/10$$

The third level model tracks individual cohorts from age 1 through age 85 and age 85+, and uses fertility and mortality information.

It is very important to insist and to realize that the very simple model on the higher level is not inaccurate. Rather, it is uncertain since the change in the growth rate depends on a number of uncertain factors. However, given a growth rate profile, the model correctly outlines the population evolution. In other words, it is the uncertainty of the input rather than inaccuracy of the model structure, which is reflected on the top level. On the lower level the relationship between uncertainty and complexity changes. While complexity is increased, uncertainty still remains but it is within a reduced range. Even if the dynamics of the population on the lower level is properly represented in terms of age cohorts, the question of attitudes towards family planning and the impact of education, religion and other factors, still remain uncertain. In other words, uncertainty goes deeper and deeper and still remains there. Uncertainty cannot be removed by increasing complexity. What is achieved, however, is that the range of uncertainty is reduced and the assessment could lead to more feasible, realistic results. For example, on the higher level one can assume a dramatic population growth rate change, i.e., dropping to zero in say 10-15 years. But the analysis on the deeper level would indicate, however, the impossibility of such an assumption in view of the dynamics of the age cohort nature of the population. If the age distribution pyramid is broad-based (i.e., percentage of population of young people is much higher than that of older people), then the population growth will continue for a period of time even if family size is transformed overnight to the replacement level. This is obviously due to the fact that the number of girls at an early age range is much higher than the number of women in the reproductive age range and since these girls will move into the reproductive age cohort, the number of children will still be as high if not higher than before even if family size is reduced. This is a well-known phenomenon which has to be taken into account when making assumptions on the policy level.

The approach then is the following: using the population model on the lower level, a number of alternative scenarios regarding attitudes towards family

planning are analyzed and the family of population growth rate time profiles is used as an alternative inputs to the population model on the top level. This prevents unreasonable and unsubstantiated assumptions from the higher level while still leaving enough room for uncertainty considerations. The approach taken is to focus on the policy level with additional assessment on the lower level for the assumptions that need to be better justified. Essentially, analysis has been conducted in terms of the growth rates of the relevant factors with the justification of growth rates changes provided by the analysis on the lower level.

In this work we will use this kind of approach for carrying capacity aspects as will be discussed subsequently.

4.6.1. ABOUT THE MORE GENERAL EQUATIONS IN OUR GLOBESIGHT MODELS

Let us return again to our "familiar" population equation.

$$pop_t = pop_{t-1} * [1 + rpop_{t-1}/100]$$

which in general could be formulate in the following

$$pop_t = pop_{t-1} * [1 + rpopm_{t-1} * rpop_{t-1}/100].$$

This equation looks simple (and indeed it is) and can be grasp intuitively and easily understandable. But often we underestimated the underlying concept.

From the mathematical point of view it is an integrated equation that represents the dynamic variation on time of the variable pop_t (we can forget that this is population and to think in general). This is obvious. But, why is it this? Because the evolution of this variable on time depends of the initial value -the initial quantity- of this variable and then, mathematically speaking, the universal form of the description of this dynamic evolution (for all kind of phenomena's in which the evolution on time of the variable depends on the quantity of the variable that we have initially) is an exponential law, which integrated form is the form that we are using here and in general in our models (of course if the variables that we would like to represent follow this kind of evolution).

We will use the multipliers, i.e. parameters, i.e. $rpopm_{t-1}$, in order to take into account the possible or normal variation in time of the time constant ("the rate") that define the intensity of the variation.

4.7. SCENARIO ANALYSIS

Scenario analysis should accommodate a multitude of factors -conceptual (verbal), relational (models) and numerical (data)- that can be interrelated in a coherent manner. It integrates two complementary components of a comprehensive scenario analysis (the yin and the yang - see Figure 4.10.): verbal vision scenarios (VVS -also called narrative scenarios) along with the use of models for numerical assessment (sometimes referred to as quantitative analysis). Lack of one or the other renders a scenario analysis incomplete.

Figure 4.10.: Relationship between verbal and quantitative scenarios
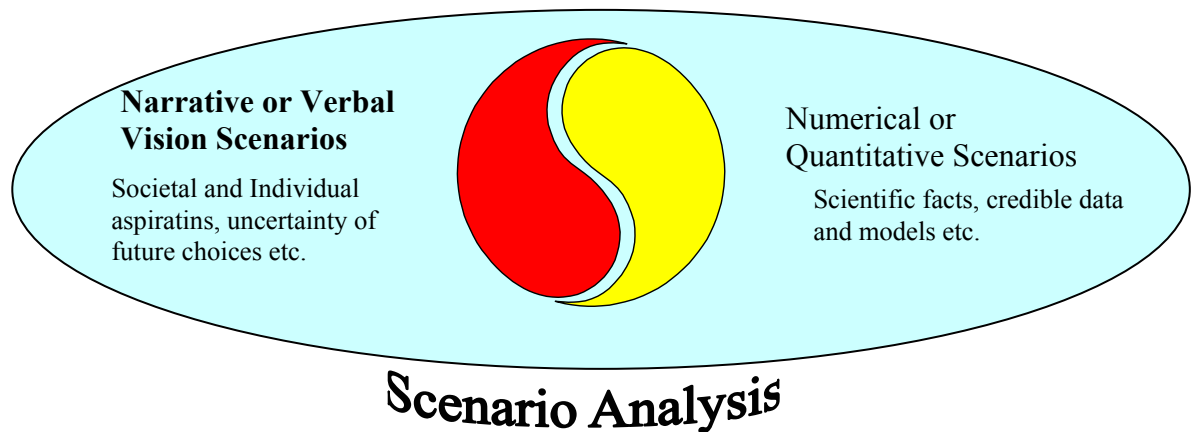
Unless the alternative futures presented are documented as feasible (not forecasted and perhaps not necessarily even highly probable) and solidly taken into account based on scientific knowledge they will lack the required credibility. On the other hand, if they are based solely on aspects of reality which can be presented in numerical form, they will not address important—indeed, crucial— factors of society, political and individual aspirations, uncertainty of societal and individual choices that are yet to be made, future events, etc., as outlined in world vision scenarios. What is needed is an approach which is broad (general) enough, yet logically consistent indicating the "causality flows"—what depends on what, how the future evolves in time, represent feedbacks and other interdependencies, etc.