Education on Globalization and Sustainability for Engineers

by
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1. Introduction

ABET requirements specify the need for engineering students to understand globalization and its impacts on science, technology, employment and socio-political contexts. An approach has been developed at Case Western Reserve University (CWRU) in which students get insight into globalization and sustainability by working on problem solving for a range of global issues—from climate change to AIDS, demographic transition, aging, carrying capacity, resource use (E.g.: water, energy, labor) etc. Dominant relationships, hierarchical modeling and techniques for combining the *quantitative with the qualitative* are used. A teaching tool has been developed with models and real-life data, which the students use in classroom exercises, as well as on a research project as a course requirement. The approach has been used for several years in undergraduate, university-wide course. The opportunity is provided for the students to interact with peers in foreign countries on the selected global issues via the Internet.

In Section 2 we will discuss the methodology used. Hierarchy and multilevel modeling approach is described. Section 3 discusses the Integrated Process briefly. Section 4 describes GLOBESIGHT the reasoning support tool used in detail. Section 5 discusses the Scenario analysis and Section 6the teaching experience.

2. Methodology: Towards Integrated Assessments with Reasoning Support Tools

2.1 characteristics of Global Earth/Human Issues Systems; Uncertainty and Goal-Seeking (or Decision Making) 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.

The main characteristics of these 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 the 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 and nature) is best understood in terms of the reflexivity concept (Figure 2.1). 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.

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. 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 change is sufficiently large and the consequences are felt over a relatively large 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 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.

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 for 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.

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 that represent the process, which the goal-seeking system uses to pursue its goal. This is within the domain of 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 (decision-making) 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 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 model cannot proceed to the next step without the human's actions and 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 shown in Figure 2.2 and 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 these studies. In traditional scenario analysis (Figure 2.2) 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 processes used in the policy analysis (Figure 2.3) the future course is outlined in time increments; the human is but a sub-model 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 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 arrive 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 continues 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).

2.2 Complexity and Multilevel Hierarchy Modeling

Global environmental change is most certainly a complex phenomenon. Understanding global environmental change requires the notion of a complex system. The starting point is the notion of a system as a relation among items or objects. A complex system is then defined as a relationship among the systems. Items that 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 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 decision-making process 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 ("surprise behavior"). A simple system in the sense of being faithfully described by a small set of equations can be chaotic (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. The behavior of a complex system can be considered on at least two levels: level of subsystems; and the level of overall systems. Conversely, a hierarchical system which has two or more levels can be legitimately considered complex.

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 not 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 that allocate the responsibilities to subsystems commensurate to their information processing and decision-making capacities.

Multilevel modeling also provides a basis for time effective management and credible policy development in complex situations.

2.3 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 only as good as its component sub-models. The problem of the validity of such an integrated model goes much beyond that. The key problem is in the linkages which integrate the sub-models into the overall integrated model. While the phenomena within disciplines could be modeled 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 possesses 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 sub-models. Even the simple links between well-defined, fully determinate models can lead to fundamentally different behavior.

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

- Development of a multi-level, 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 multi-level framework currently being used to research cybernetics of global change is shown in Figure 2.4. 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.

3. Integrated Assessment as a Process

The concept of integrated assessment is then introduces in recognition of the less than reliable forecast capabilities of integrated 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 integrated modeling plus sensitivity analysis. The process is akin to the decision support approach used in management science and practice.

4. GLOBESIGHT – A Reasoning Support Tool

This section describes the reasoning support tool that has been built with the philosophical and the methodological foundation described in the previous sections. The tool is named **GLOBESIGHT** short for **GLOB**al fore**SIGHT** and is useful in understanding the past, evaluating the present and looking into different feasible (not probable or just possible) futures**.** GLOBESIGHT requires the human to represent the subjective and qualitative aspects of the issue at hand whereas known data, procedures, models are inherent in GLOBESIGHT. Together with the “human-in-the-loop” one could explore different futures represented by We describe the architecture of GLOBESIGHT next.

4.1 GLOBESIGHT Architecture

The GLOBESIGHT analysis support system consists of the following modules (see Figure 4.1).

4.1.1 Information Base

This module 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 of past and present data such as demographic (census population, expected population growth rates, cohort, fertility and mortality distribution, past, present and expected, infant mortality rates, etc.), economic (gnp, gnp by sectors, growth rates, etc.), resources (fuel, water, forest and mineral wealth, etc.), etc., is available. Our database consists of data from 196 countries, geographically or economically contiguous regions that are aggregated from the countries (some aggregations that we have used are 21 regions, five continents, developing countries, countries in transition, and developed countries, etc.). The source for our data is UN, World Bank, World Resources Inst., World Watch Inst., journals, CIA World Fact Book, books, reports, journal articles, etc.

4.1.2 Models Base

The models base consists of models of sub-systems such as population/demographics, economics, resource supply and demand evolution, etc. These models in essence are representations of reality and can be used to look at possible different futures to analyze policies, effects of certain actions, etc. They are in the form of algorithms that start from the current state of the system and compute future evolution. The models are scientifically based and are based on the principle of "model only what is modelable". The models are available in multiple levels. For example: the population model first level consists of a simple first order growth rate equation.

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

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 highly uncertain with all the uncertainty embodied by 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 :

$$pop_t=pop_{t-1}+ pop_{t-1} *[crbrt_{t-1} -crdth_{t-1}] \qquad (2)$$

and the rate of population growth is computed now as

$$rpop_{t-1}= [crbrt_{t-1} -crdth_{t-1}]/10 \qquad (3)$$

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

Similarly there are models of different sub-systems at different levels such as economics, food, water, energy, oil, climate, (Figure 5.2) etc. The multiple levels may be based on resolving the following:

(a) geographical disaggregation (from global to continents/regions to nations to state/provinces, etc.),

(b) sectoral disaggregation (e.g., disaggregating total water use in a country to water use in the nation by domestic/municipal, industrial and agricultural sectors, total energy supply resolved based on energy mix, national gnp resolved into sectors of industrial, service, and agricultural gnp etc.), and

(c) complexity

It is important to realize that there is no magic bullet for disaggregation. In general this is a hard problem.

4.1.3 Issues Base

Using the models base as basic building blocks one can construct systems to study specific issues in detail. This is illustrated in Figure 4.2 where the multi-level models are represented.

4.1.4 Functionality Base

The functionality deals with three issues 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 (Figure 4.3) 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 (Figure 4.4). Features such as rivers could be overlaid on the graphs. Standard geography views are included. For example aerial photographs and satellite photos can be overlaid. Interpolation routine to shape key inputs such as rate of economic growth, etc. using multiple interpolation methods are available. Goal seeking, wherein a desired goal (e.g. emission target) with a single input (e.g. economic growth) has been implemented.

4.2. GLOBESIGHT – Implementation Details

GLOBESIGHT[1] 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.

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[1] Contact the author for more details at Systems Engineering, OLIN Building Rm# 608, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106-7070, USA.

5. Scenario Analysis

Scenario analysis should accommodate a multitude of factors—conceptual (verbal), relational (models) and numerical (data)— that can be inter-related in a coherent manner. It integrates two complementary components of a comprehensive scenario analysis (the yin and the yang - see Figure 5.1): 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.

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.

6. Teaching Globalization and Sustainability for Engineers

Using the methodology and the approach described in Sections 2-5 we have put together a Junior level course in the Systems & Controls Program of the Electrical Engineering and Computer Science Department at Case Western Reserve University. This course over the past five years has been offered nine times and has enrolled about sixty students annually. Of these eighty percent are engineers with students from across the university (political science, management, environmental studies, etc.) also participating. Labs using GLOBESIGHT is required part of the course. Students in groups of three to five define a course project with the help of the instructors, write a project proposal, meet with the instructors periodically and make a project presentation to the class along with a 20-25 page project report. Topics the students have chosen in the past have been: Global Energy needs, Ultimate recovery of oil, Effect of AIDS/HIV on Sub-Saharan Africa, Carrying Capacity of the Earth, Mining needs, Aral Sea Basin Vision, Nile River Problematique, Reemergence of Tuberculosis, Bioterrorism (Smallpox and Anthrax), etc. The course has been commended by ABET reviewers during the last review in 2000-01 as being unique. Students write an essay on what they have learned in the course. This is available on genie.cwru.edu and has been extremely positive.

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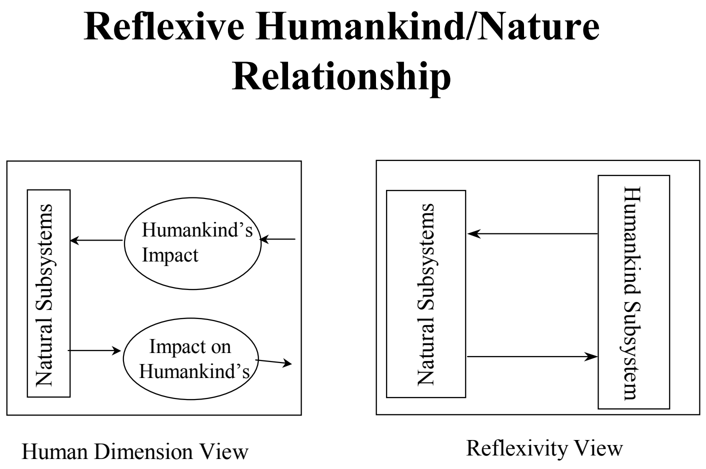
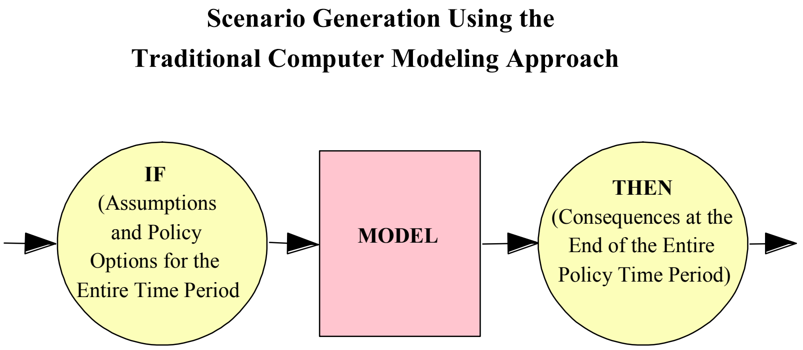


Reflexive Humankind/Nature Relationship

Figure 2.1: Reflexive relationship between humankind and nature



Scenario Generation Using the Traditional Computer Modeling Approach

Figure 2.2: Scenario Generation Using the Traditional Computer Modeling Approach

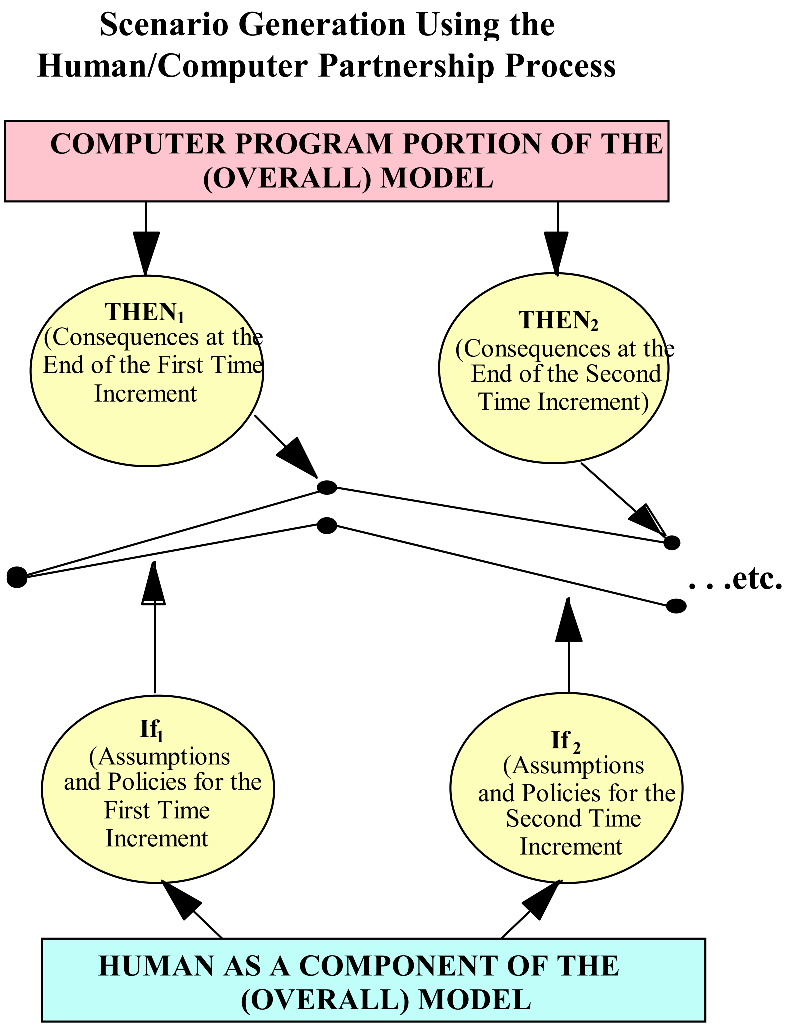


Figure 2.3: Scenario Generation Using the Traditional Computer Modeling Approach

Global Change as a Multi-level (Stratified) System

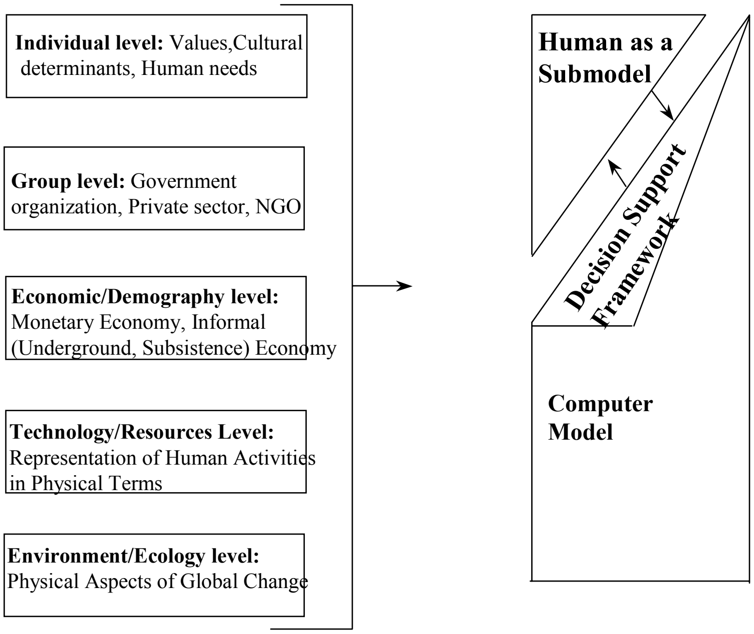


Figure 2.4: Hierarchical levels

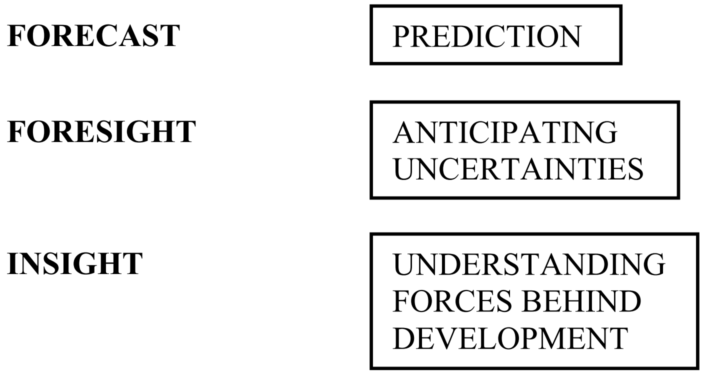


Figure 3.1: Difference between forecast, foresight, and insight

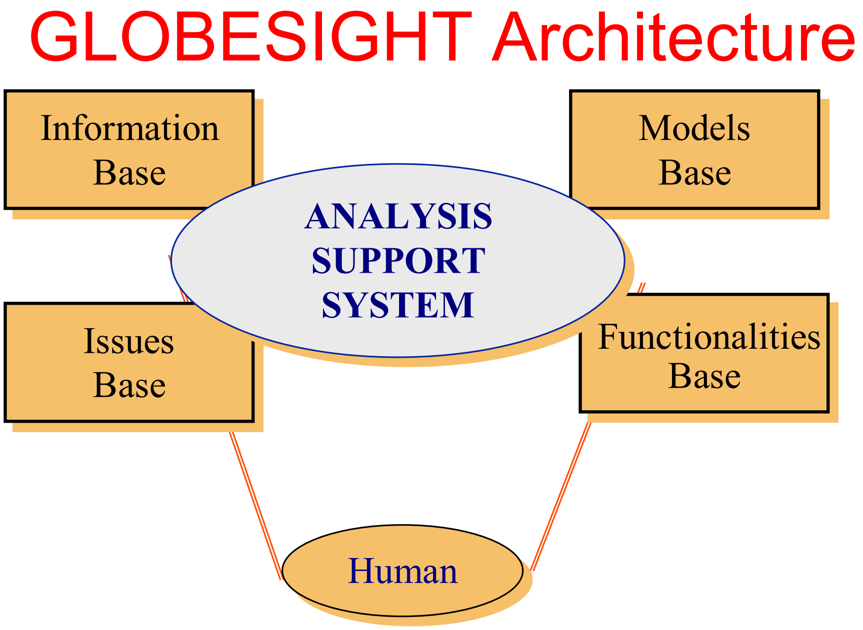
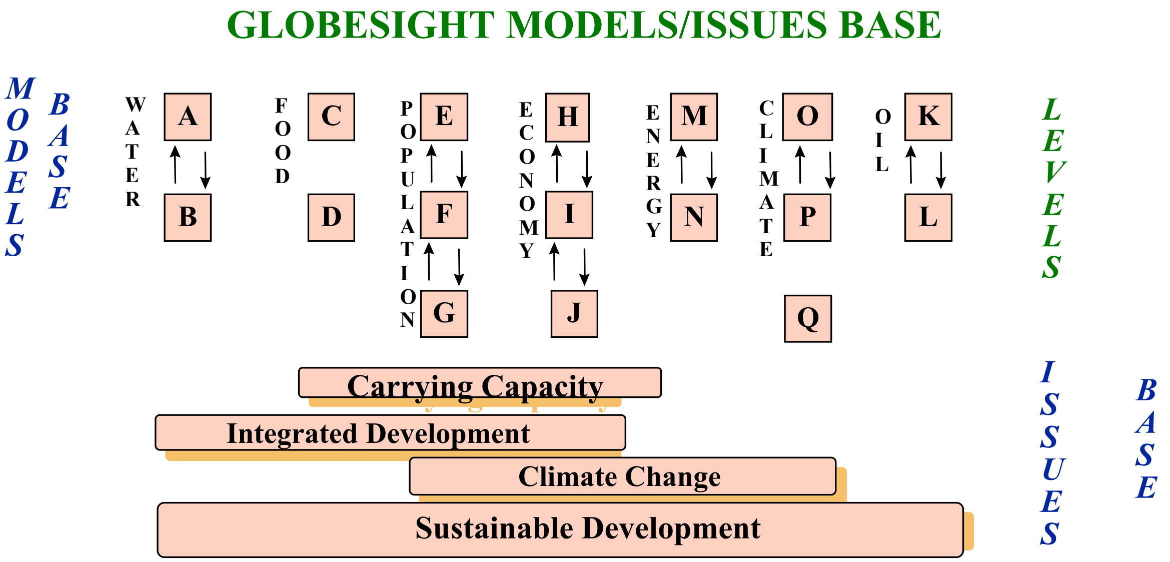


Figure 4.1: GLOBESIGHT architecture



A. Water Stress & Scarcity, Global
B. Water Stress & Scarity, Regional/National

C. Maximal Food Production Model
D. Food Data-base/Model
E. Population, Growth Rate
F. Population, Crude Birth/Death Rates
G. Population, Age Cohorts

H. Economy, Growth Rate
I. Economy, Production, Consumption
J. Economy, Trade

K. Oil Reserves, Ultimate Recovery, Global
L. Oil Reserves, Ultimate Recovery, Regional

M. Energy, Total Primary
N. Energy, Mix

O. Greenhouse Gases Emissions/Concentration
P. Climate Change
Q. Long-term Concentration Equilibrium

Figure 4.2: Relationship between multi-level models base and issues base

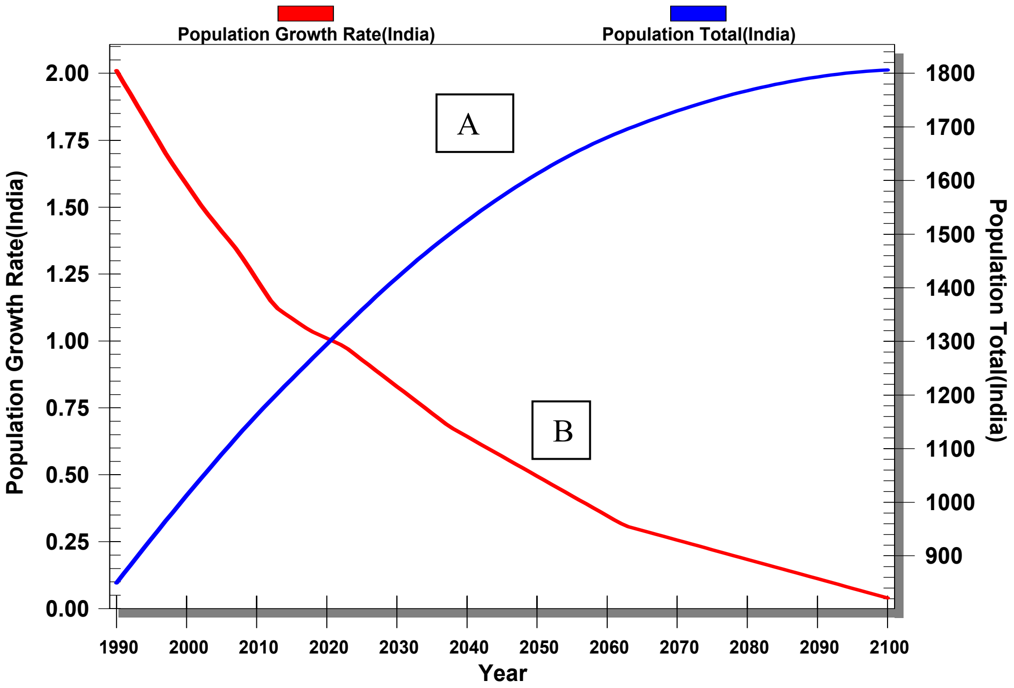


Figure 4.3: Multi-axes graph of Population (A) and Population Growth Rate (B)

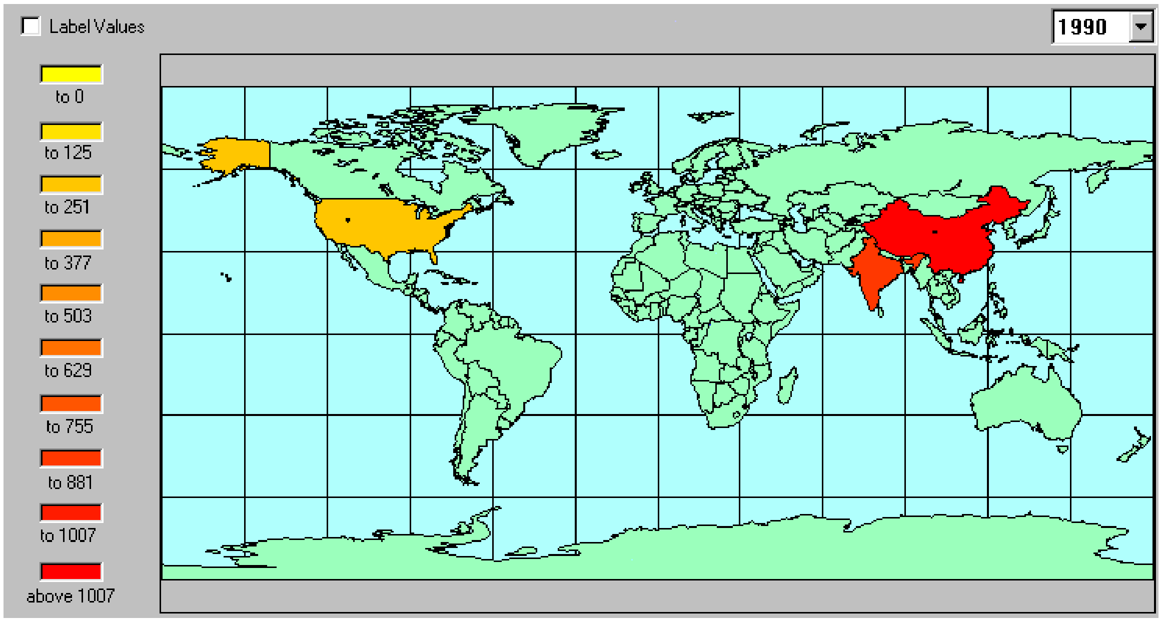


Figure 4.4: Geographical Information System (GIS)

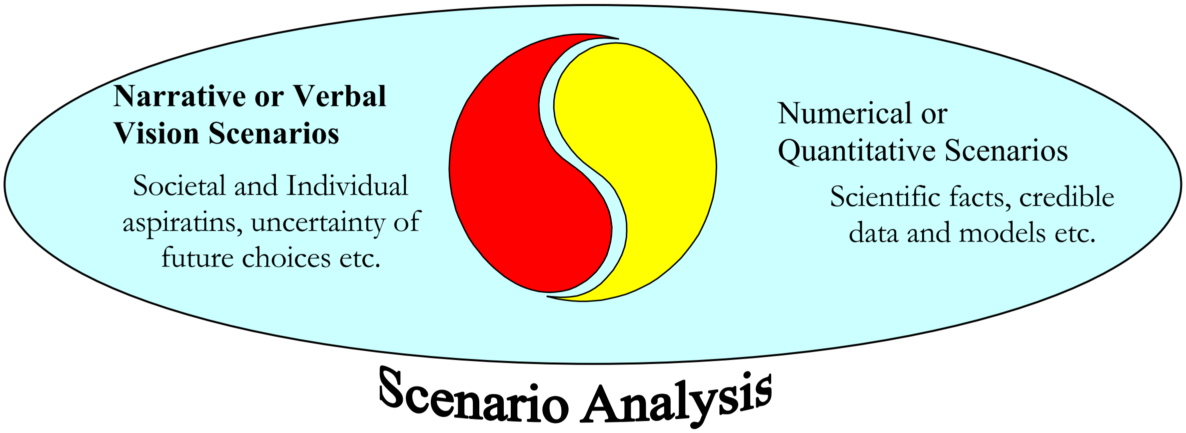


Figure 5.1: Relationship between verbal and quantitative scenarios