TERRA 2000 The 21st Century

TERRA2000

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PREFACE

TERRA2000 has been a project sponsored by the Directorate-General Information Society of the European Commission in response to the pressing need to align the creation of a global networked knowledge society (GNKS) and its accompanying New Economy with the requirements for achievement of sustainability generally and of sustainable development in general. Specifically, the project has sought to create (by use of formal analytical methods) the insights necessary to inform and guide policy-making[1] leading ultimately towards the optimisation of ISTs contribution to sustainability.

This is the final version of what during the project has been a living document that provided an internal point for reflection on ongoing development - in this case, the development of models and the role of modelling in TERRA. A second purpose (no less important) was to provide feedstock for TERRA2000 outputs and results.

The project has used several ‘living documents’ to facilitate its work and the exchange of ideas among the consortium and with interested parties. In addition to this document, these have included:

- A Story of TERRA document that presents the overall vision of the project, explains the key concepts, describes the modus operandi and the intended outputs and presents key results from project work.
- A scenarios document that describes the scenario analysis framework and collects narrative and structural descriptions of scenarios formulated and analysed within the project.
- An integrated modelling platform, comprising the project databases and the integrated IFs for TERRA model (the centrepiece of a range of models developed and used in the project), together with its associated tools and help system.
- An electronic ‘weak signals file’ that notes and discusses phenomena that may signal emergent aspects of the relation of the GNKS and sustainability.
- Specific thematic scenario analysis reports associated with the three central themes (Human Capital, Equity and Growth, Information Age Sustainability).

In addition, the project has produced a range of external results:

- New understandings of its topic areas in general abstracted as TERRA2000 ‘Concept Sheets’;
- Specific insights into the mechanisms by which sustainability, IST and the GNKS interact expanded in ‘Insight Primers’; and
- Summaries of the state-of-the-art in relation to specific decision-making areas (or policy issues), presented as TERRA2000 ‘Policy Briefings’ that identify the range of possibilities; show the firmer probabilities within them; and (by way of references to Concept Sheets and Insight Primers) point to any background material that may be needed for evaluation.

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[1] TERRA2000’s understanding of Sustainable Development is discussed in Concept Sheet 1; its understanding of the relationship of Information Age to sustainability is discussed in Concept Sheet 2; and issues concerning policy formation in Concept Sheet 3.

This former living document has now become a final Tools and Models document for the TERRA project that discusses the role of modelling in the project and that gives conceptual discussions of the various types and instances of tools and models.

The audience for this document includes not just TERRA project members, but policymakers who need to understand the scientific basis for TERRA2000 policy briefings. It also includes broader scientific and policy research communities interested in seeing how the phenomena identified in TERRA2000 concept sheets (including the themes themselves) are rendered in models, how those models support the scenario formulation and analysis activities or wishing to build on the conceptual and concrete model architectures and code developed in the project to extend the policy analysis and to improve the models.

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EXECUTIVE SUMMARY

1.1. TOOLS IN TERRA2000

The world is uncertain and information is diffuse. To inform policy and discussions, various sorts of thinking/discussion aids, consistency checks and validation are necessary. In particular, understanding evolution of a complex system requires a combination of data, models and scenarios.

The development and use of these models in TERRA follows the TERRA backbone from hindsight to foresight via insight on several levels. Hindsight is based on databases and statistical analyses, insight uses models and scenarios to describe underlying mechanisms and their linkages and foresight is based on projections (not forecasts) of future evolution and the impact of policy levers under different circumstances.

Analysis begins with fairly simple statistical data summaries, high-level, aggregate and/or specific models[2] and scenarios and trend extrapolations – in addition to being essential precursors to more detailed analysis, they also help us to identify "things we didn't know that we knew." They also pose puzzles about phenomena that they can only render through assumptions, such as commoditisation of intellectual property, diffusion of new ideas, chains of secondary innovation, coevolution of network connections and cooperative behaviour, etc. On the other hand, they have the virtues of being explicit, easy to comprehend and (providing appropriate assumptions are made) reasonably robust ways of addressing the 'facts' and their implications.

By contrast, the 'hidden features' of the GNKS are best addressed through more detailed[3] and disaggregated analyses. These are based on complex methods and are also more sensitive to assumptions and other uncertainties – they are a way of investigating "things we know that we don't know."

More generally, models help to unlock latent tendencies in data, test our understanding of system structure and dynamics, and discuss policy issues in ways that expose assumptions and rules of inference. Models can use and/or generate data, but not all models do so. As used here, the term model refers to a quantitative description of all or part of the TERRA system, divided among three broad categories[4] as indicated in Table 1.

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[2] In particular, this includes the computational dominant relations and integrated models and the scenarios developed in the thematic work packages.

[3] More strictly, theoretical models are detailed in description of the underlying mechanisms, while computational (esp. integrated) models are detailed in scope.

[4] It is also possible to divide the models by form: i) *computational models* of varying degrees of complexity, completeness and fidelity to empirical data; *empirical models* designed to test specific hypotheses against real data and develop predictions from proven hypotheses; and *theoretical models* intended to derive useful conclusions from a set of starting assumptions and rules of inference.

Table 1: Model types

Level	*Purpose*	*Horizontal Span*
Conceptual ("what should be")	Sheds light on complex ideas lacking structure, data, etc.; guide lower level modelling, generate rigorous/ qualitative insight relating to general principles.	Features of 'deep' structure common to all thematic domains (e.g. networking, globalisation, etc.)
Policy-orientated ("what could be")	To give (external) meaning in terms of mechanisms and levers	Policy domains: decision proc., ministries, levers, jurisdictions
Outcome-orientated ("what would be")	Quantify/illustrate spillovers, support signpost/trigger planning, gaming, illustrate for wider audiences.	Linkages across IS↔ sustainability domains

These are not disjoint: Figure 1 shows how some of the models[5] developed in the TERRA project fit into this framework.

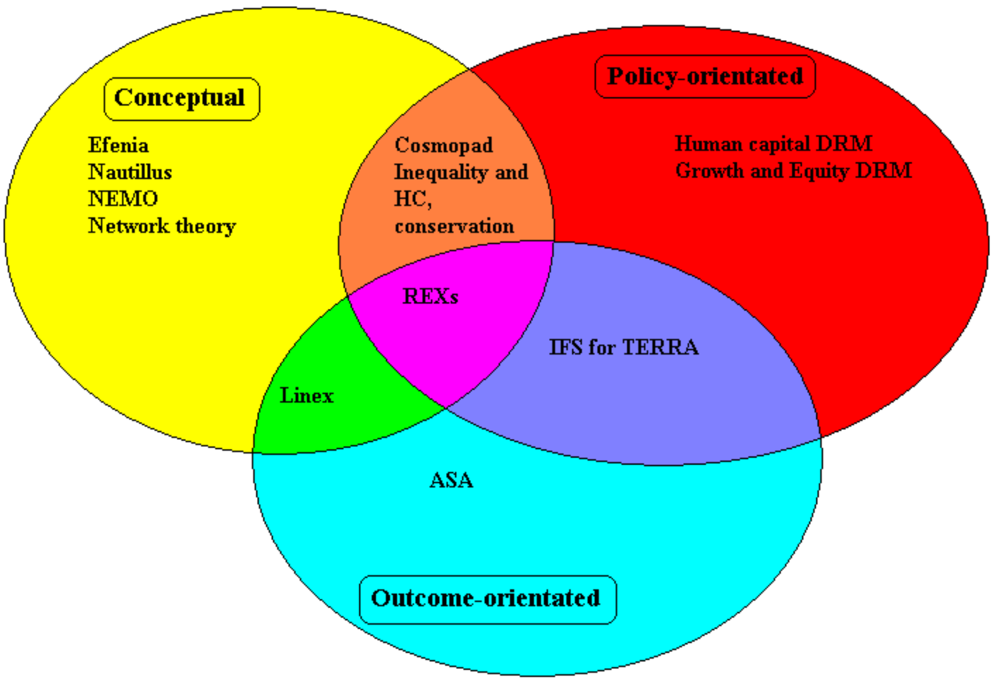


Figure 1: Model types in TERRA

[5] More details on these models are provided in Table 2 below.

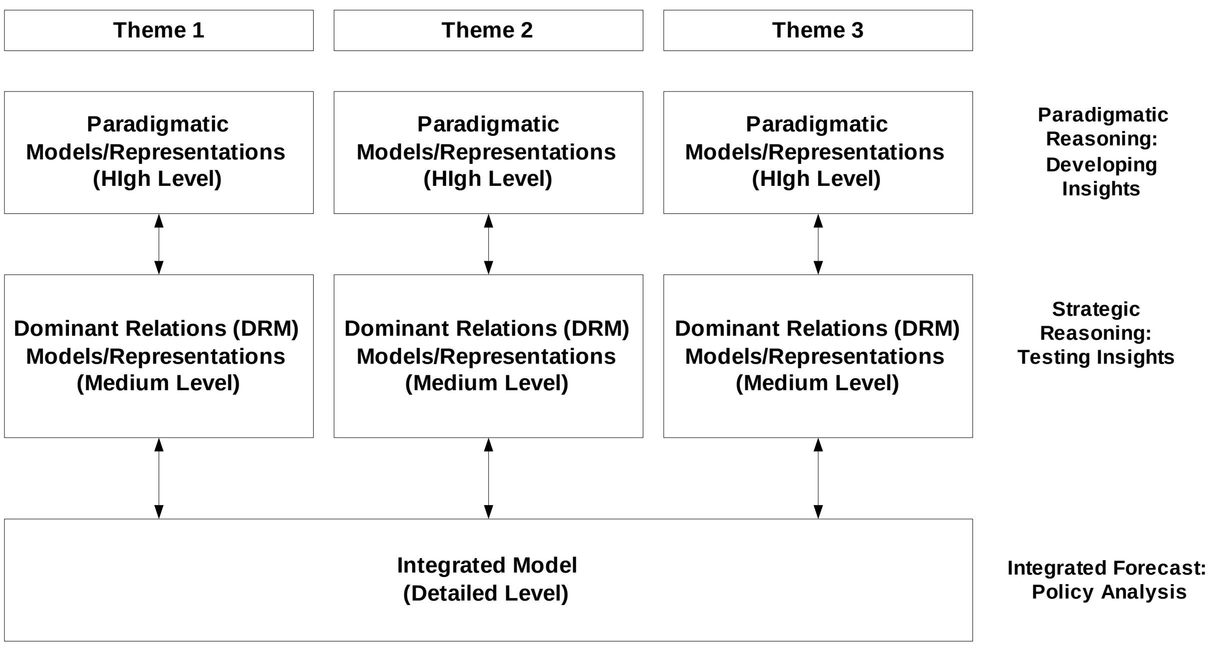
As the perspective evolves from prediction to policy analysis, the tools evolve as well. As many of the phenomena tackled by TERRA are not readily measurable – and some are not even quantifiable in the usual sense – so not all the models are (or should be) at the same stage of development. It is no accident that the latter stages of the project saw an increase in the amount of paradigmatic and theoretical modelling, as this is the appropriate way to approach those fundamental developments that emerged as essential based on computational modelling and accompanying scenario analysis.

EVOLUTION OF THE MODELING STRUCTURE

TERRA2000 began as a dual-purpose scenario and modelling project, of which an integral part was an ongoing record of modelling activity. The first year of the project produced a document on tools and models (TERRA (2001)), which underwent several revisions to describe emerging models and tools and facilitate their integration. Following project re-organisation in the second project year, TERRA (2002) reported the restructured three-level methodological foundation for the project.

This restructuring reduced the emphasis on modelling *per se* and substituted an incremental, cumulative, thematic development path emphasising dominant relations policy-orientated models in each of three themes (Human Capital, Equity and Growth, Information Age Sustainability) scheduled for staggered attention. For each theme, paradigmatic models or representations (sometimes with the help of computerised modules and sometimes without) and dominant relations representations were tapped to provide analysis of the potential leverage of principal policy levers.

Despite these changes, TERRA has developed a strong stable of tools forming a conceptually but not physically integrated model set and tool system within a three-level, three-theme architecture that manifests TERRA commitment to empirically-based representation of the unfolding of the networked knowledge society and to facilitating creative insight concerning processes that are fundamentally transformative.



SPECIFIC MODELS IN TERRA

In TERRA, models were used all along the 'backbone.' For hindsight, the main integrated model (IFs for TERRA) and the related indicator-based model focussing on sustainable development (ASA) provide comprehensive tools for exploring the past and the *status quo*. Of course, the empirical models (esp. Linex and the panel equations estimated for the study of the relation between human capital inequality and growth), being estimated using historical data, provide summaries of past outcome and trends.

Table 2: classification of some principal TERRA models

Model	*Type*	*Focus*
Conceptual System Dynamics Model of Planetary Agricultural & Biomass Development (COSMOPAD)[6]	Computational - Insight	Human-induced worldwide biomass production and its effects
Effects on Environment of Internet Applications (EFENIA)[7]	Computational - Insight	Environmental requirements of key elements of GNKS infrastructure for IT applications
Networking Effects Model (NEMO)[8]	Computational - Insight	Examination of competing SD paradigms: constraints and technological potential
Dominant relations human and social capital model(s) (DRM)[9]	Computational - Dominant relations	Foresight into power of immigration, education, and growth in labour productivity to overcome projected skill shortages and examination of social capital and equity development.
Advanced Sustainability Analysis (ASA)	Computational - Integrated	Crosscutting SD analysis based on 'master equations' relating welfare and environmental stress to indicators of economic, technological and social development.
Collective Modelling Platform	Computational - Integrated	Collecting and integrating systems dynamics models
IFs for TERRA (IFs)	Computational - Integrated	Large-scale integrated global modelling system adapted to GNKS features and policy levers. Serves data exploration and scenario development/analysis.

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[6] See Weiler and Tesch (2003).

[7] See Tulbure (2002).

[8] See Tesch and Descamps (2001).

[9] See Mesarovic *et. al.* (2003).

Model	Type	Focus
Resource Exergy Services (REXs)	Empirical - Integrated macro econometric forecasting model	New formulations of important components of economy-energy models: capital accumulation, resource use and technology-innovation
Linex macro production function	Empirical	Accounting for role of physical work in growth
Human capital inequality model	Empirical	Panel model of relationship of human capital inequality to growth.
Network structure, behaviour coevolution	Theoretical	Game-theoretic model of evolution of co-ordinated behaviour and network structure, used to analyse network aspect of SD
Inequality and conservation	Theoretical	Game-theoretic model of inequality and conservation of commons
Networking Activity Understanding and Testing Instrument Linking Logic reasoning and the Use of Simulation (NAUTILLUS)	Theoretical-computational	Simulation tool for examining growth and properties of random networks.

Integrated computational models

Computational models produce numerical outputs, and are thus appropriate for engaging with stakeholders whose actions rely on quantitative representations of the *status quo ante*, the impending future and the impact of policy options. These models include integrated data/indicator models used to give a broad view over the holistic evolution of the Information Society. The underlying framework is IFS for TERRA, based on the International Futures (IFs) model. This system combined a very wide range of data with sophisticated multi-sectoral modelling to provide a tool for exploring both the past and the future. For TERRA, this was modified in order to highlight the centrality of the GNKS, to provide a 'policy cockpit' for exploring the impact of policy scenarios and the design of adaptive multi-policy programmes. A related view concentrating on indicator-level description of sustainable development is presented (within the overall framework) by the Advanced Sustainability Analysis (ASA) approach, which rests on two basic postulates for improving sustainability: non-decreasing welfare and non-decreasing environmental stress. Conditions suitable for empirical analyses and policy formulation are derived mathematically from four identities ("master equations") that relate the environmental stress variable (ES) chosen for an analysis to the basic indicators of economic, technological and social development. The explanatory power of the theory relies on new concepts and formulas for sustainable policy making and new empirical results for comparisons among countries and regions as well as between policy targets and results achieved. The use of such identities in ASA and other 'dominant-relations' type models necessarily abstracts from the specifics of 'bottom-up' behaviour. In complex, multi-layer system and broad range of actors make interlocking decisions that determine overall system behaviour over time. Dominant relations models and trend analysis provide descriptions of this behaviour. Explanation uses models estimated from empirical data to test theoretical formulations of dynamic behaviour. Within the TERRA system of models, such explanation is provided (in an integrated, sustainability-orientated sense) by REXs.

What the different types of models tell us

The TERRA computer modelling toolkit contains models at three levels: paradigmatic, dominant relations and policy-analytic. These names combine different characteristics, so a word of explanation of how they interact is in order. Essentially, the paradigmatic models are used for ‘playing with ideas’ to investigate the implications of different ways of formalising concepts (networking, globalisation, immaterialisation, etc.) that are difficult to measure and which lie well below the level at which data are collected.

This document outlines the development of tools over the full TERRA project. It seeks to convey conceptual foundations, development paths, and the status of tools that the TERRA project has created for the follow-on use of others.

TABLE OF CONTENTS

2. FOUNDATION

The world that TERRA2000 attempts to understand (with the aid of scenarios supported by modelling) is shown in the following Figure. This document will subsequently elaborate on the modelling and tool system,[10] but Figure 1.1, by representing the focal points of the TERRA2000 project, suggests the categories into which applications of those modules fall. Although there are many feedbacks and bi-directional relationships in the modelling beyond those represented, the simplified figure also suggests an analysis sequence of importance to TERRA2000 for scenario development. Specifically, both the development of a networked, knowledge society (influenced, of course, by investments in R&D and human capital) and the availability of resources (especially energy) will affect economic development. Social and economic development are strongly linked. The impact of human economic and social systems on the broader environment will depend heavily on the interaction of complex processes of dematerialisation/immaterialisation and rebound.

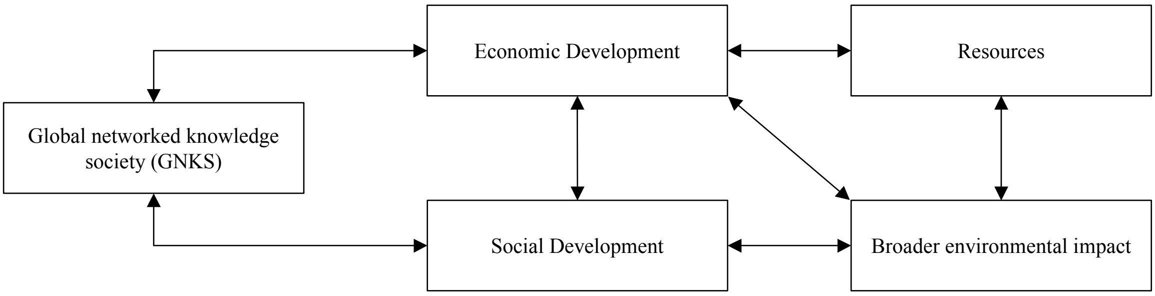

Figure 2.1 TERRA2000 Focal Points

1.1 A CONCEPTUALLY COMPLETE AND IDEAL TOOL KIT

It was useful for TERRA to begin with identifying some general principles concerning the models and other tools that the project team wanted for analysis of the above system. There are four main principles that came out of that discussion: (1) the combination of three levels of analysis that the project identified as insight development, strategic reasoning, and integrated policy analysis (the three levels will be elaborated below); (2) integration of the substantive modules and supporting tools across the TERRA substantive focal points and across the three levels of analysis; (3) reliance on both a rich database and scientific/theoretical supports for substantive modules; (4) flexibility and user-friendliness in tool use. The rest of this section discusses each of these principles and shows the conceptually ideal tool kit that the modelling and tools team of the project elaborated from them.

[10] Deliverable 7.1-3 described the "Prototypes for Integrated Model and Tool System. That was a "living document" that had undergone several revisions in an effort both to describe the emerging models and tools of the TERRA2000 project and to facilitate their continued integration. Deliverable 15.5-3, "Tools and Models Living Document," reported on a restructuring of the methodological foundation for the project into the three-level system described in this final version of TERRA Tools and Models documentation.

1. A Three-Level Analysis Approach. The TERRA2000 project adopted a three-level approach to the development of its modelling and tool system. The three levels interact and reinforce each other. Figure 1.2 below shows this three-level perspective[11].

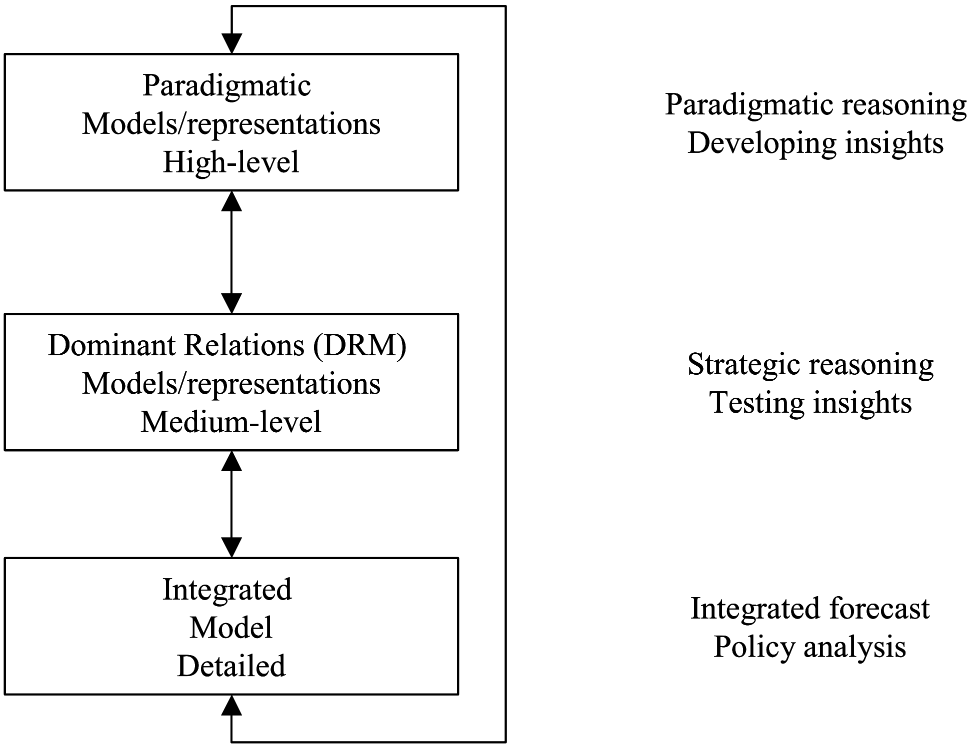

Figure 1.3 The Levels of TERRA2000 Modelling

We understand that *paradigmatic reasoning* with respect to the forces shaping the long-term global dynamics of human development systems should guide the development and use of all models (whether mental or formal). These insights are not always made explicit, but it is obviously best when they are. We also recognise that demographic forces (and recently, the demographic transition) have driven human development over a very long period. We believe, however, that we should recognise at least two other key forces at the paradigmatic level. The first is the increasing importance of the growth of human knowledge and technology. Increasingly this has allowed extensive networking, both electronic and more traditional variants, to reach levels far beyond past human experience. It has been critical for the TERRA project to develop models that help users of them tease out paradigmatic insights concerning these interrelated forces of knowledge growth and technology, especially networking expansion. The second paradigmatic force lies in the external and one might also say eternal constraints (on both input and output sides) that the environment places upon the activities of human beings. For instance, useful energy or exergy has been and remains a critical constraint upon human production. Subsequent sections of this report will outline the model development efforts of TERRA with respect to paradigm-level analysis.

Even during periods of dramatic transformation, a relatively limited number of dominant relations tend to shape dynamics around specific issues. The team recognised that it must explicitly represent such dominant relations in models, in order to identify *strategic* paths. It believed further that such dominant relations should be transparent to users of all of our

[11] As proposed by Mike Mesarovic (see Deliverable 8.2).

models, including the more integrated ones. The very understanding of these dominant relations provides foresight and basic strategic reasoning capabilities for users of a modelling and tool system. Within TERRA, and especially within the theme analyses, our models represent dominant relations concerning the connections: i) among the growth of knowledge and the extent of human capital and the productivity of the economy; ii) between economic growth and the distribution of access to its fruits and those of the knowledge society in general; iii) between the resource base of fossil fuels and the production of energy; and iv) between the size of the economy and its environmental impact. We need to communicate such relationships clearly to users and make it possible for them to modify our representation of them, to some degree, in their own analyses.

Finally, in order to be most helpful in policy analysis and forecasting, it was determined that the TERRA toolkit should include *integrated* tools with a level of detail that allows users to intervene in ways that approximate the ability of social actors to influence human development. The reality is that no integrated, general-purpose model will ever have all of the intervention options desired by users. Figure 1.2 calls this the "detailed" level, but it is not typically a "micro-level" model in the sense of being truly agent-based. Nonetheless, we should strive to develop as many of the intervention options of interest to social actors or agents (including political decision-makers) as possible, in collaboration with the very social actors who have the capability for intervention. Modelling systems at this level are of necessity shaped by paradigmatic insight and structured by dominant relations. It is therefore important that understanding and representation at those higher levels be made clear in the policy-oriented model.

2. Integration of Tools across Issue Arenas and Levels of Analysis. The close integration of global systems may be a cliché, but is also a reality. Moreover, it is during periods of transformation and rapid change that insight into the linkages across systems becomes most critical. From inception the focus of TERRA has been on the integration of knowledge, economic, social, and environmental systems. It was desired, insofar as possible, that at least some of the modelling tools support the study of their relationships. The TERRA project embraces a holistic, multi-disciplinary approach to complex systems.

Similarly, insofar as possible, it was desired that the tools for analysis at the three levels not only inform each other, but actually link to each other.

3. Data and Scientific/Theoretical Basis. Further, the tool bench or tool kit of the TERRA project should incorporate and use a rich database and, as much as possible, should draw upon established scientific/theoretical foundations. The "as much as possible" disclaimer is important. Especially at the insight level, it is important to stretch the limits of established foundations and data availability. And even at the integrated level, it is important not to omit key driving forces or linkages simply because others have not fully ploughed the scientific field before us. It was often said within TERRA "we should model only what it is really possible to model." While that recognises the importance, as TERRA has, of data and scientific bases, the philosophy, were it applied exclusively throughout TERRA and not primarily at the dominant relations level, would effectively preclude breaking truly new ground. We must recognise that periods of rapid technological, economic, and social transformation are periods in which insight and synthesis must reach beyond historical, data-based analysis. Our tools were developed so as to supplement maximum use of well-established forecasting methods with the capability of analysts to explore new insights concerning transformative processes and critical dynamics around complex systems.

4. Flexibility and Ease of Use. Tools will not be used unless they are easy to use. Larger-scale modelling systems, in particular, have historically not been easy to use, either in strictly technical terms or in terms of the intelligibility or transparency of analysis they support. TERRA modellers have sought to enhance usability in several ways, including simplicity of interface, modular construction, full and easily available documentation, and open, ideally internet-based access.

The Overall Tool Kit. In light of the above purposes and principles, the complete and ideal modelling and tool system was conceptualised at the Denver modelling meeting in December of the first project year to look like the structure portrayed in Figure 1.3. Its key components are the user interface, the database, scenario result files, and substantive modules that cross focal points of the project and levels of analysis.

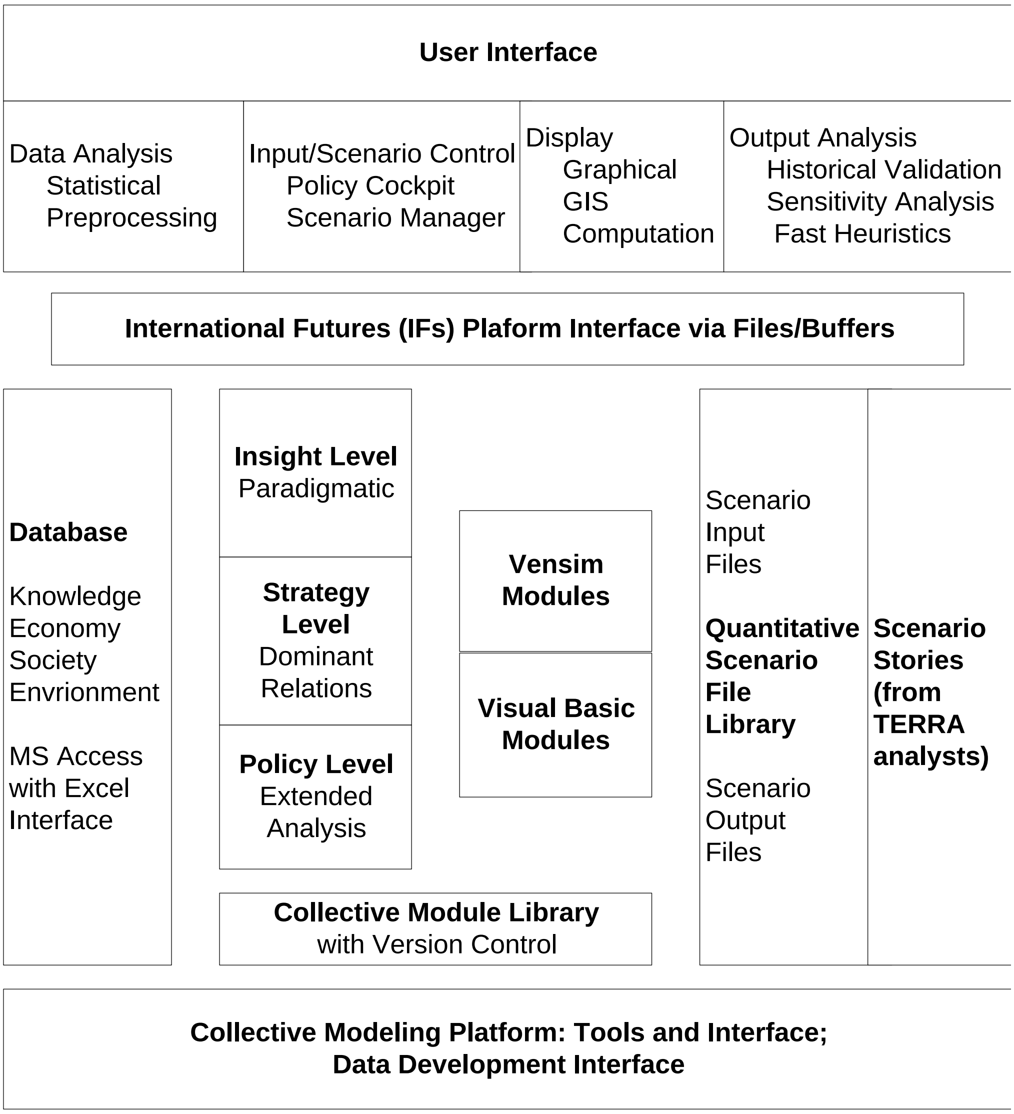

Figure 1.3 The Desired or Ideal Modelling System and Tool Kit

The desired **interface** was described as having

- Data analysis capabilities for working with an extensive country-specific database. It would allow cross-sectional and longitudinal statistical analysis, with graphical display as well as statistics computation. The interface would also have "preprocessing" capabilities that automate the preparation of data from multiple sources with their inevitable missing values and incompatibilities for substantive modules.
- Input or scenario control for selecting policy interventions and managing scenarios. The "policy cockpit" would facilitate the policy interventions, while the scenario manager would maintain sets of alternative interventions and facilitate revision and extension of scenarios.
- Display capabilities in a variety of formats. The formats would include traditional tabular and graphical ones, as well as maps using a basic geographic information system (GIS) capability. In addition, it would be important to have flexible computational ability for aggregating, combining, and transforming outputs.
- Extended output analysis features. It would be important to be able to undertake historical validation studies. Similarly, TERRA modellers want users to be able to do sensitivity analysis across single or multiple inputs and to have tools for rapid analysis of results.

The **database** would have

- Extensive geographic coverage, representing large numbers of data series across the focal points of the project and for as many countries as practical.
- Considerable temporal coverage. When possible the data would extend from 1960 (even earlier for a few variables) through the most recent year.
- Consistent format. The database physically connected to the larger modelling and tool system should be in a consistent format for easy use by other tools.

The **scenario or result files** should evolve over time in support of the scenario analysis of the TERRA project. They would also be:

- Generated by sets of assumptions that it is possible to revise and/or extend over time. These scenario input files should be maintained in the library of quantitative scenario files, which will also include selected scenario output or forecast files generated with the models from the scenario input files.
- Clearly linked to the scenario stories that are told on the scenario analysis side of the TERRA project.
- Easily managed via the scenario manager of the user interface.
- Easily compared and contrasted via the display tools of the interface.

The **substantive modules** would be:

- Developed with a clear notion of the distinction between paradigmatic, dominant relations, and extended policy analysis levels.
- Modular in structure. Although it will never be simple, it should be possible for a user to swap in a new module with limited difficulty.

- Flexible in origin. Our desire would be to allow the combination of modules created on the Vensim collective modelling platform with those created in the International Futures (IFs) modelling platform. We will make this clearer later.

2.2. THE ART OF THE POSSIBLE

The conceptually desired toolkit did not fully materialise in the course of the TERRA project, for two primary reasons. First, the goals were always understood to be highly and perhaps unattainably ambitious, in spite of the great motivation of members on the modelling team to accomplish them. Second, resources were shifted early in the second year of the project from the task of physical as well as conceptual integration of the TERRA modelling system into the more immediate development of analyses and reports on three themes rooted in the focal points of the TERRA enterprise.

Nonetheless, the project made very considerable progress with respect to tools and models and ends with a substantial legacy on which project members and others can build. Large portions of the "ideal" toolkit truly did come into being. The rest of this report will elaborate what was accomplished and what was not.

3. DEVELOPMENT OF MODELING AND TOOLS IN TERRA

This chapter presents the modelling and tools of TERRA in the categories of the three levels that Chapter 1 introduced (paradigmatic insight, dominant relations foresight, and integrated analysis). Because of the prominence given to dominant relations modelling after the project re-organisation, the discussion begins with that technique as applied to each of the themes. In reality, all three modelling techniques were often applied within each theme as well as to integrative analysis across the themes.

One of the reasons for discussing tools and modelling by analytic level is that comprehensive project documentation of the tools and models is almost entirely written for the specific models and the analysis levels they most prominently support. This chapter will refer the reader to that extensive documentation as the tools and levels are discussed.[12]

3.1. DOMINANT RELATIONS MODELING WITHIN THE THREE THEMES

The GLOBESIGHT (for GLOBal foreSIGHT) system, described in Mesarovic, et al. 1996, was the basis for dominant relations modelling in Themes 1 and 2. See also the GLOBESIGHT project website at http://genie.cwru.edu/globesight.htm. Because modelling and tools development for TERRA took place within the three themes, it is to the documents of the various themes that we must look to see the details of that development. Within TERRA documentation there are two reports in two tasks that are of particular utility in demonstrating the development and use of dominant relations models:

> Task 12.3, "Dominant Relations and Insight Modelling," applies DRM to the human capital issues of Theme 1. The report also discusses the insight modelling done for Theme 1 (to which we will return later).
>
> Task 12.4, "Human and Social Capitals for Sustainability in the Information Age," applies DRM to the human capital theme again, but also to social capital issues of Theme 2 and even to the natural capital concerns of Theme 3. This document is therefore the best source of information on dominant relations modelling within TERRA.

Theme 1: Human Capital. Work on the three themes began in a staggered fashion, so that subsequent themes could advance thinking across the focal points of TERRA, taking advantage of work in earlier themes. Theme 1 (Work Package 12) therefore began first and also delivered its final report first. The interested reader should look to the final deliverable for Task 12.3, "Dominant Relations and Insight Modelling" to see the fruits of the application of the approach, used for Theme 1 in close coordination with insight level modelling. Quoting from the Executive Summary of that report:

> For the foresight analysis, an approach has been developed for TERRA referred to as *Dominant Relations Modelling, DRM,* which focuses on the key relationships to avoid

[12] Anyone interested in seeing an illustration of documentation across the three model types/levels can look to the equation documentation of GLOBSIGHT, NEMO, and IFs for TERRA in a TERRA Project Place document under Task 15 called "Integrated Description of Model Equations." That document was prepared early in the second project year, however, and equations from each of the three tools advanced considerably thereafter, making the model-specific documentation more useful for most readers.

being bogged down in a myriad of often-time uncertain details. For the insight analysis, two *Insight Level Models*, ILM, are developed to analyse:

1. The impact of networking on IST growth
2. Labour productivity growth in the knowledge-based global economy.

ILMs are designed consistent with the strategy-oriented DRM model. The DRM model has 10 regions, two of them being the EU and EU Candidates. ILM models are on a global level. A prototype model of the global information networking is developed on the insight level using new and still ongoing network science. A full-scale model will be used in Theme 2: Growth and Equity in the Information Age.

The GLOBESIGHT strategic analysis tool is used for model building.

A family of ILM and DRM models are arranged in a multilevel architecture, Figure 1 [2.1 here]. They are developed as a package but are not integrated in a computer code. The relationship is left in the hands of the user who provides expert judgment of feasible, anticipated developments in the areas of science, technology, values, socio-political, changes in values, etc. On one hand, this multilevel structure provides the possibility of reasoning about the long-term paradigmatic developments, while on the other hand it does not commit the user to a fixed integrated structure, as is usually the case.

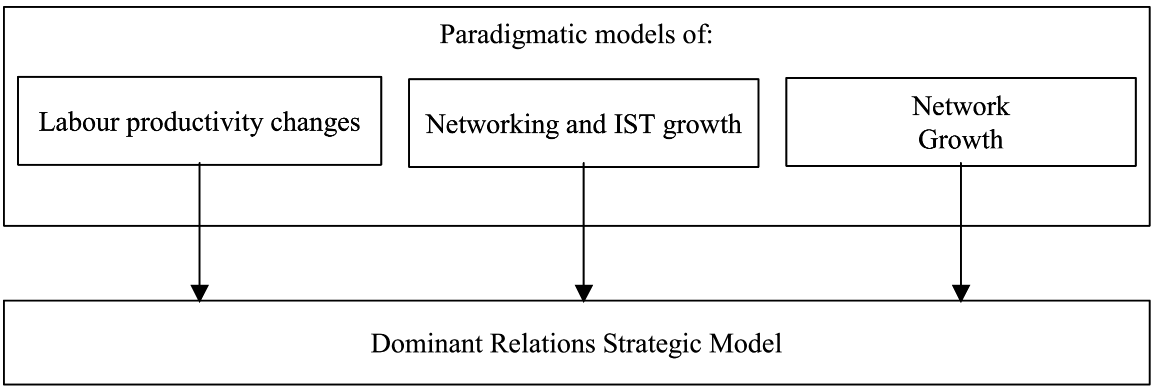

Figure 2.1 Human capital models

The report contains conceptual underpinnings, a complete list of equation specifications, block diagrams and causality flows to meet the transparency requirements (crucial for the acceptance of policy recommendations by decision-makers and the public-at-large), estimation of parameters and test runs for each of the models to demonstrate their functioning.

The demonstrated application of dominant relations modelling in the report is an analysis of a posited increasing shortage in ICT human capital, looking at immigration, changes in investment in education, and differing assumptions concerning growth in labour productivity as policy levers for overcoming the shortage. The DRM analysis concludes (p. 26) “In spite of the best educational practice the deficit is overwhelming.” For Western Europe by 2050 the study computes that total immigration needed to address the posited deficit would be 25 million. The scenario report for this theme, written in cooperation with Theme 2 under Task 12.4, “Human and Social Capitals for Sustainability in the Information Age” develops the analysis further.

In addition, the reader is directed to Section 8.2 of “Dominant Relations and Insight Modelling” on an emerging Network Growth Topological Model, using the insight modelling tools (to be discussed below). The goal of this effort was to create a user-friendly tool that simulates the behaviour of networks and their growth. An initial step was to simulate the problems/situations/networks discussed in Barabaśi's (2002) excellent book *Linked: The New Science of Networks*. The insight modelling in this area is also further discussed in the Task 12.4 report.

Theme 2: Equity and Growth. Theme 2 (Work Package 13) has not submitted a separate methodological report, but decided to follow the same general approach indicated for Theme 1, with a model "designed particularly for the analysis of the four alternative visions for the futures developed by Franz-Josef Radermacher." (From the Task 12.4 Report). Specifically, that theme builds its methodology around a measure based on the Lorenz curve, which has been used effectively in physics for the self-similarity phenomena. The starting point for the measure is the cumulative income distribution described by the Lorenz Curve.

Theme 3: Information Age Sustainability. Theme 3 (Work Package 14) moved ahead rapidly in developing its model and tool structure. Its tool kit draws heavily on the Advanced Sustainability Analysis (ASA) approach developed by the TERRA2000 team members at the Finland Futures Research Centre (FFRC), with connection to and support by Insight modelling and IFs for TERRA. Kaivo-oja, Luukkanen, and Malaska (2002), building on earlier work[13] provided a theoretical framework and empirical analysis of the potential of economic growth and welfare policies to contribute to sustainability.

Deliverable14.1, "Thematic Analysis Report on Information Age Sustainability," very comprehensively describes the models and tools, as well as analyses, for Theme 3. In particular, Chapter 2 documents ASA in detail. In addition, a working report for Theme 3, "Equations for ASA and IFs for TERRA" present the combined equations for the linkage of the ASA system and the environmental representations within IFs for TERRA.

The Advanced Sustainability Analysis (ASA) approach is based on two basic postulates for improving sustainability: non-decreasing welfare and non-decreasing environmental stress. The conditions suitable for empirical analyses and policy formulation are derived mathematically from four identities ("master equations") that relate the environmental stress variable (ES) chosen for an analysis to the basic indicators of economic, technological and social development. The explanatory power of the theory relies on new concepts and formulas for sustainable policy making and new empirical results for comparisons among countries and regions as well as between policy targets and results achieved.

Environmental Stress (ES) is a multiple attribute concept. For instance, total material flow, energy flow, energy consumption, total water use, CO_2 emissions, waste discharge, etc. can all be used as attributes. Welfare, the other main concept of the ASA approach, is also a multiple attribute concept. The Human Development Index, economic consumption, the Index of Sustainable Economic Welfare (ISEW) and other welfare measurements can be used as its attributes (see e.g. Hoffrén 2001).

The ASA approach offers decision-makers a new and advanced tool for policy formulation and analysis regarding sustainable development issues, taking account of their connections to conventional economic and welfare policies.

As identities, the master equations have the status of high-level dominant relations: they are logical tautologies and thus need no empirical or other verification. Their utility lies in their

[13] Malaska, Kaivo-oja, and Luukkanen 1999, Kaivo-oja, Luukkanen and Malaska 2001a, 2001b

unfolding and the connections they establish among measurable quantities. They were chosen because of their important relationship to economic and social factors and policies.

The first three equations relate the environmental stress-indicator to the supply side of the economy. The first relates environmental stress to GDP and population via a quantity called the environmental stress intensity of production. The second equation relates environmental stress to employment and an indicator of the environmental stress intensity of employment. With some special environmental stress-measures, e.g. material flow or energy, the latter (ratio) term can be interpreted as an indicator of automation. The third equation relates environmental stress to economic structural change via a shift of employment from environmental-stress-intensive to less intensive sectors of the economy in order to achieve sustainability. The fourth identity represents the demand side of welfare via two concepts: the welfare productivity of GDP and the environmental stress intensity of welfare. From each identity, important new concepts of sustainable development are derived for use in policy formulations and empirical studies.

3.2. INSIGHT MODELING ACROSS PARADIGMATIC ELEMENTS

Whereas dominant relations modelling provides a first cut into the unfolding of key trends and relationships, the purpose of insight modelling is to let the imagination soar with respect to the transformation of existing systems. Instead of the spreadsheet and data-based techniques of dominant relations modelling, insight modelling in TERRA turned to the tools of systems dynamics for rapid prototype development of thinking and exploration tools. The project decided at an early stage to use Vensim as a software package for such tool development. It also decided to let the models developed within it be less tied to data and to geographic representations than dominant relations models. Further, the connections of the insight models to particular themes are usually obvious, but less strict.

One way of looking at the insight-level models of the TERRA project is as collectively presenting an alternative or even successor to the World 3 modelling system of the *Limits to Growth* project. Specifically, they constitute an alternative that maintains the emphasis of World 3 on environmental constraints, but augments it with an understanding of the influences, both positive and negative, of an unfolding global networked knowledge society, the central focus of the TERRA project.

Within TERRA a suite of Vensim-based insight models emerged during the course of the project, with three major threads:

- NEMO (**N**etworking **E**ffects **Mo**del), followed and augmented by NAUTILLUS (**N**etworking Activity **U**nderstanding and **T**esting **I**nstrument **L**inking **L**ogic reasoning and the **U**se of **S**imulation). Documentation for NEMO can be found in the (original organisation) Work Package 2, Deliverable 2.1 "Initial Working Paper for Network Effects Model Representation" and, for equations in the Task 15 working paper called "Integrated Description of Model Equations." Documentation for NAUTILLUS, emerging only at the end of the TERRA project, can be found in a power point presentation on "Networking & Network Models." Tom Tesch developed both models with support from Pol Descamps. The Network Growth Topological model developed for Theme 1 was, in some respects a foundation within a Barabaśi-influenced networking system model for the NAUTILLUS effort.
- EFENIA (**EF**fects on **EN**vironment of **I**nternet **A**pplications). This model is best documented in a project paper by Ildiko Tulbure, "The Information Society and the Environment: a case study concerning two Internet Services."

- REXS (**R**esource **EX**ergy **S**ervices). For documentation see "An introduction to REXS, a simple system dynamics model of long-run endogenous technological progress, resource consumption and economic growth" by Benjamin Warr and Robert Ayres.

The rest of this section will provide some basic information on these three insight threads.

NEMO. The original NEMO system provided a great deal of impetus to tool development within TERRA. As indicated above, the insight models of TERRA combine attention to the environmental constraints of global systems with attention to the unfolding, for better or worse, of the GNKS. There are, of course, two long-standing and competing paradigms concerning global futures, that of constraints and that of technological potential. NEMO, in particular, constitutes an effort to look at both within a single model. Figure 2.2 shows an overview of the model structure with both of those competing paradigmatic or worldview elements represented.

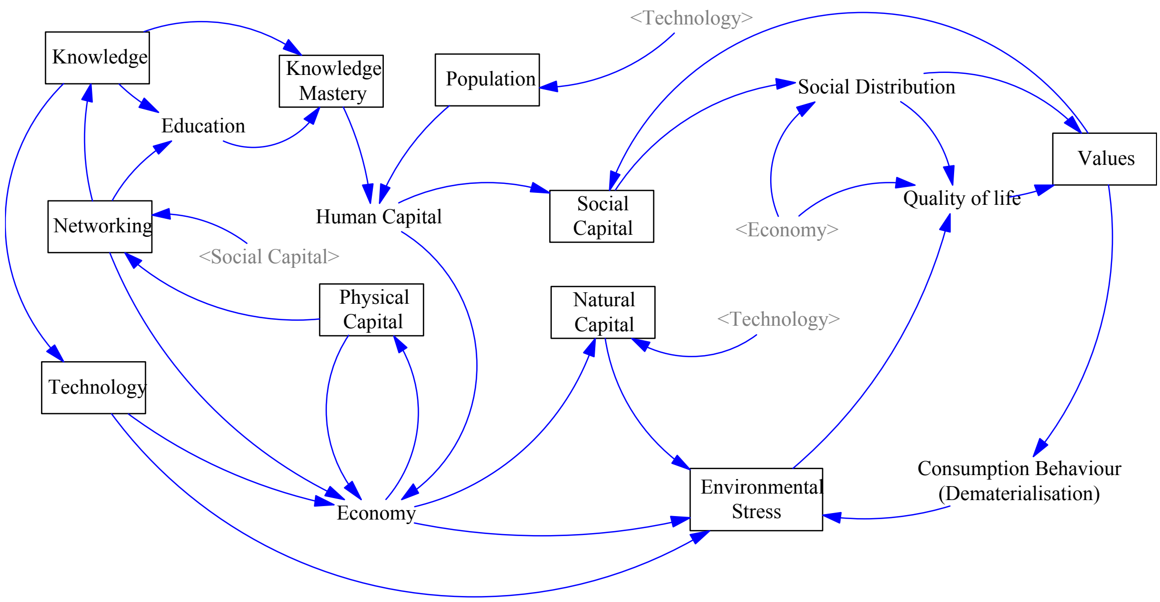

Figure 2.2 Networking Effects Model (NEMO)

The elaboration of NEMO was substantial throughout the first year of the TERRA project and the effort was highly innovative.

As the TERRA project shifted towards an emphasis on the three themes, the thread of this work was substantially redirected into the development of the Network Growth Topological model for Theme 1. Influenced by Barabaśi, the goal of the effort was "to create an user-friendly tool that allows [the user] to simulate the behaviour of networks and their growth." The engine of the model, written in Java, allows

- The creation of unique nodes (each has an unique ID)
- Nodes can be given a certain fitness
- The removal of nodes
- The creation of links between nodes
- Analysis of the size of the network
- Analysis of the number of links per individual node

- Analysis of the number of clusters in a network
- Analysis of the size of each cluster
- Identification to which cluster a node belongs
- And much more around nodes, clusters, and paths

Figure 2.3 shows some of the foundational building blocks in the network growth model

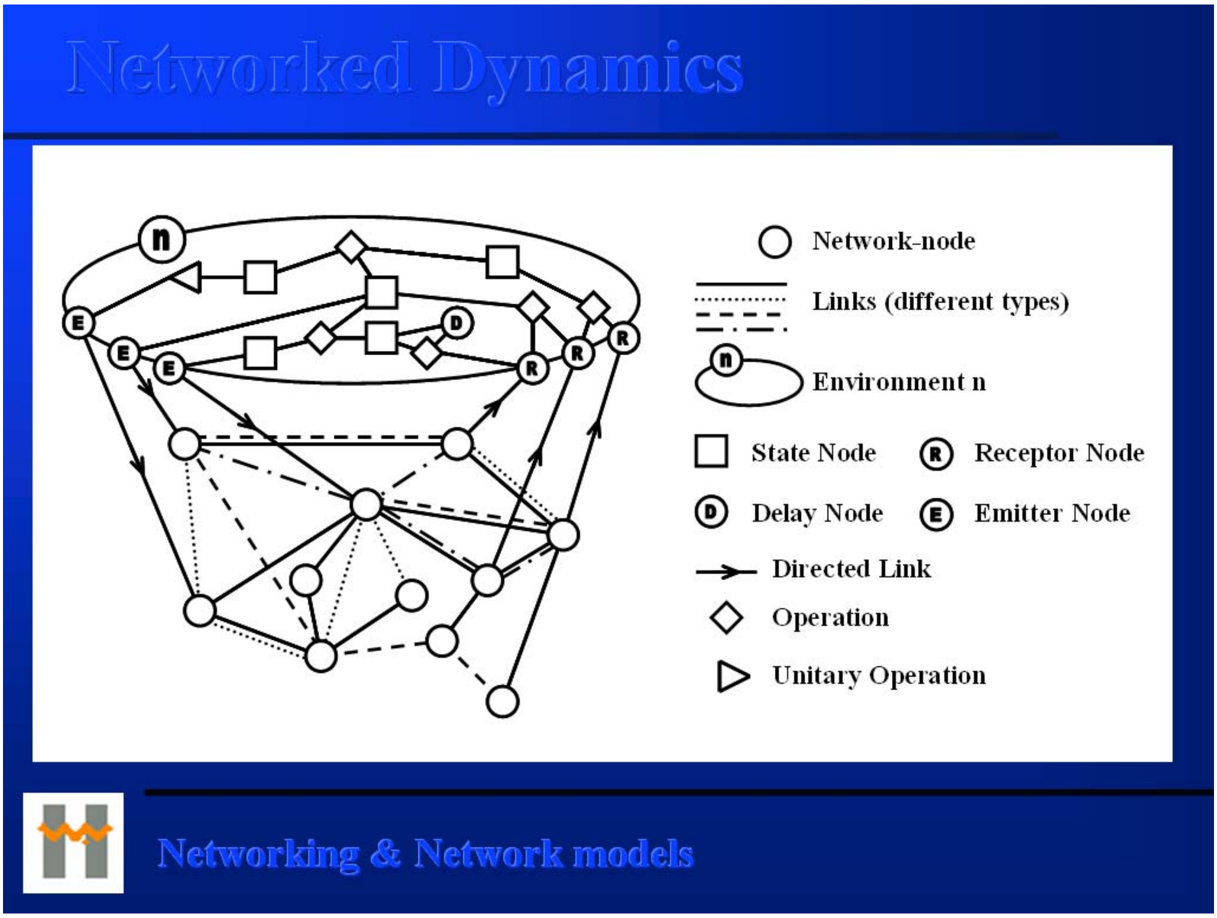

Figure 2.3 Networking Growth Model

As NAUTILLUS emerges from the networking growth model, one of the elements planned for it is the representation of time dynamics. This will be an important bridge from generic network modelling to representation of selected real world systems.

EFENIA. Whereas the networking growth models focus on what most observers would consider the potentially positive contributions to development and sustainability of the GNKS, the EFENIA model turns our attention to the more immediate environmental impact of the GNKS. Specifically, the model looks at the environmental requirements of a number of key elements of the new era's infrastructure for the use of IT-applications. Extracting from the report:

- Infrastructure for the use of IT-applications

  Ex.: Number of computers, Internet accesses

- Effective use of Internet-application: by considering two possible applications: on-line-informing (index 1) and e-working, (index 2).
- Energy and paper consumption

  Ex.: Energy consumption of computers during production and during use + energy consumption for paper production, and because of travelling to the work office of the user and non-user of e-working possibilities.

- Environmental field by considering pollutant emissions and quantity of e-scrap because of old computers.

See Figure 2.4 for a general idea of the coverage of the model.

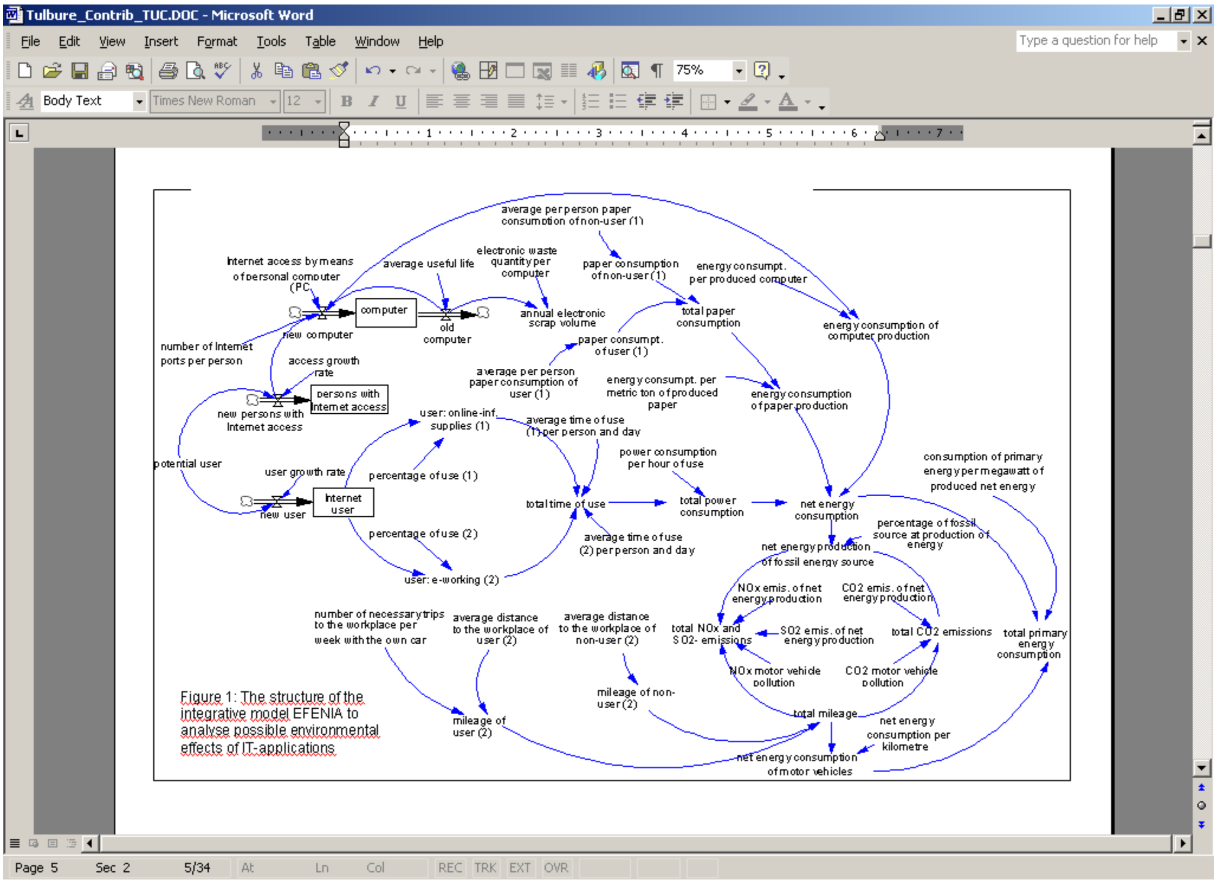

Figure 2.4 EFENIA

REXS. The self-described purpose of the REXS model is to “present new formulations of the most important components of most economy-energy models [namely] the capital accumulation, resource use (energy) and technology-innovation mechanisms.” Like NEMO, REX can be seen in part as an effort to capture both the new elements of the GNKS (such as the rapid growth of ICT capital stock) and the eternal constraints on human production, in this case that of effective energy or work capability.

The REXS models builds on substantial contributions that Robert Ayres and Ben Warr made to the TERRA database and analysis effort through their extended research into the relationship between the useful work (or exergy services) provided by the energy system and the magnitude of economic production. That research, in combination with a basic division between ICT and other capital stock, led them to formulate an image of the production function like that in Figure 2.5.

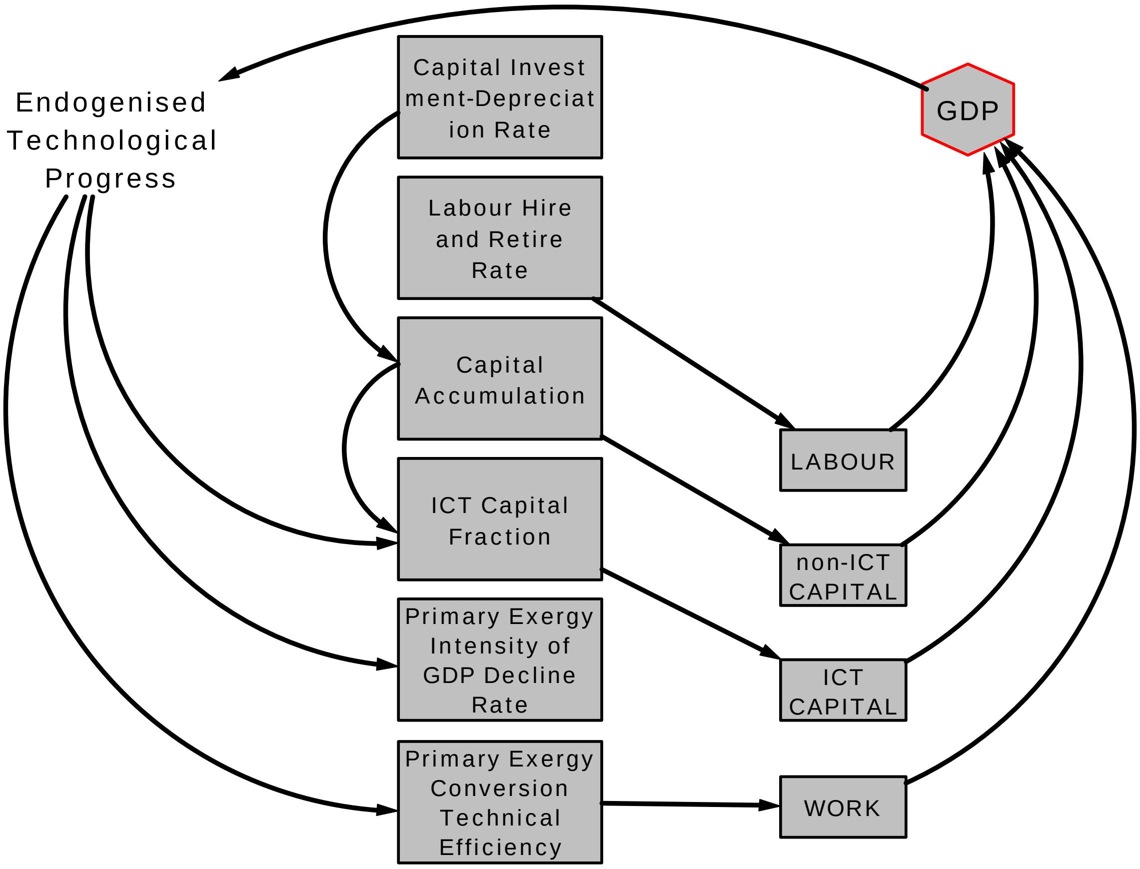

Figure 2.5 The Production Function of REXS

Once again, the insight level models of TERRA constitute tools for thinking about transformation.

3.3. INTEGRATED ANALYSIS ACROSS THE THEMES

The insight-level models of TERRA constitute tools for thinking about transformation. Dominant-relations modelling provides tools for thinking about key forces in selected issue areas. Human systems, however, evidence both continuity and change. And they are highly integrated and dynamic across the entire range of focal points within the TERRA project.

TERRA project members therefore understood from the beginning that it was necessary to attempt to bring as many elements as possible together into an integrated tool kit. Chapter 1 outlined the thinking that emerged with respect to the elements of that tool kit.

Further, the project identified two foundational pieces of software upon which it could build the integrated platform. One was the International Futures (IFs) model of Barry Hughes and the other was the collective modelling platform of the FORSIS team in Russia. This section describes the two platforms and how they were adapted for TERRA.

3.3.1. International Futures (IFs)

International Futures (IFs) is a large-scale integrated global modelling system that has been under development through four generations over more than 20 years (Hughes 1999). The broad purpose of the International Futures (IFs) modelling system is to serve as a thinking tool for the analysis of long-term country-specific, regional, and global futures across multiple, interacting issue areas.

IFs is heavily data-based and also deeply rooted in theory. It represents major agent-classes (households, governments, firms) interacting in a variety of global structures (demographic, economic, social, and environmental). The system draws upon standard approaches to modelling specific issue areas whenever possible, extending those as necessary and integrating them across issue areas.

The menu-drive interface of the International Futures software system allows display of results from the base case and from alternative scenarios over time horizons from 2000 up to 2100. It provides tables, standard graphical formats, and a basic Geographic Information System (GIS) or mapping capability. It also provides specialised display formats for age-cohort demographic structures and social accounting matrices.

The system facilitates scenario development via a scenario tree that simplifies changes in framing assumptions and agent-class interventions. Scenarios can be saved for development and refinement over time. Standard framing scenarios, such as those from the third study of the Intergovernmental Panel on Climate Change (IPCC), are available.

The modelling system also provides access to an extensive database for longitudinal and cross-sectional analysis. Insofar as possible, data represent 164 countries since 1960. In addition to providing a basis for developing formulations within the model, the database facilitates comparison of data with “historic forecasts” over the 1960-2000 period.

By far the most extensive documentation is available in the Help system of IFs itself. That includes full documentation through causal diagrams, equations, and computer code. See http://www.du.edu/~bhughes/ifs.html for access to the model and other description.

Figure 2.6 shows the major conceptual blocks of the International Futures system. The elements of the technology and environmental blocks are, in fact, scattered throughout the model.

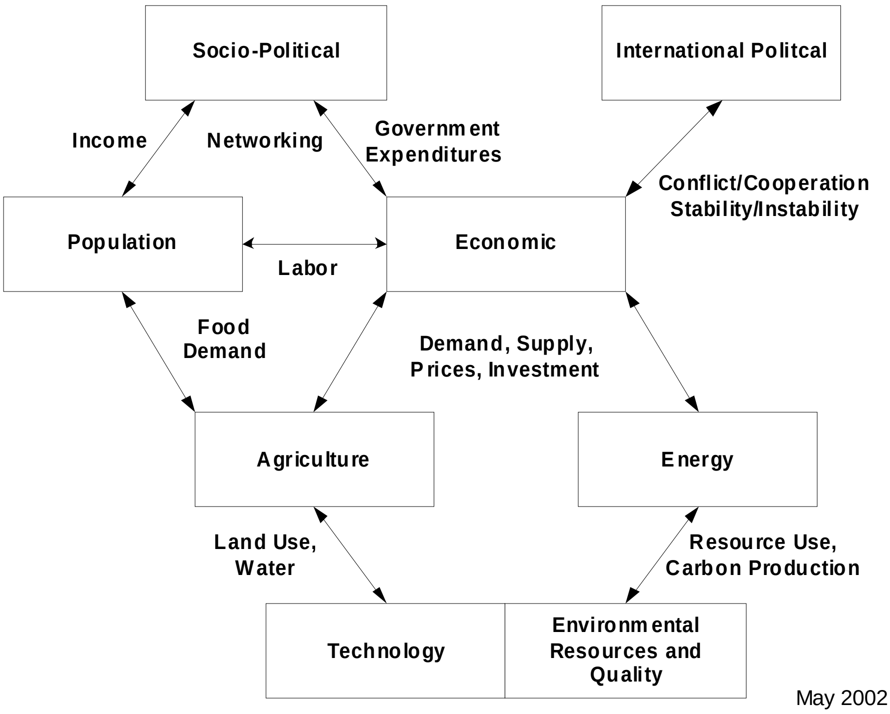

Figure 2.6 An Overview of International Futures (IFs)

The population module:

- Represents 22 age-sex cohorts to age 100+ in a standard cohort-component system structure
- Calculates change in cohort-specific fertility of households in response to income, and income distribution
- Calculates change in mortality rates in response to income, income distribution, and assumptions about technological change affecting mortality
- Computes average life expectancy at birth, literacy rate, and overall measures of human development (HDI) and physical quality of life
- Represents migration
- Shows HIV/AIDS
- Includes a newly developing sub model of formal education across primary, secondary, and tertiary levels

The economic module:

- Represents the economy in six sectors: agriculture, materials, energy, industry, services, and ICT (other sectors could be configured, using raw data from the GTAP project)
- Computes and uses input-output matrices that change dynamically with development level
- Is a general equilibrium-seeking model that does not assume exact equilibrium will exist in any given year; rather it uses inventories as buffer stocks and to provide price signals so that the model chases equilibrium over time
- Contains a Cobb-Douglas production function that (following insights of Solow and Romer) endogenously represents contributions to growth in multifactor productivity from R&D, education, worker health, economic policies ("freedom"), and energy prices (the "quality" of capital)

- Uses a Linear Expenditure System to represent changing consumption patterns
- Utilises a "pooled" rather than the bilateral trade approach for international trade
- Has been imbedded in a social accounting matrix (SAM) envelope that ties economic production and consumption to intra-actor financial flows

The agricultural module:

- Represents production, consumption and trade of crops and meat; it also carries ocean fish catch and aquaculture in less detail
- Maintains land use in crop, grazing, forest, urban, and "other" categories
- Represents demand for food, for livestock feed, and for industrial use of agricultural products
- Is a partial equilibrium model in which food stocks buffer imbalances between production and consumption and determine price changes
- Overrides the agricultural sector in the economic module unless the user chooses otherwise

The energy module:

- Portrays production of six energy types: oil, gas, coal, nuclear, hydroelectric, and other renewable energy forms
- Represents consumption and trade of energy in the aggregate
- Represents known reserves and ultimate resources of the fossil fuels
- Portrays changing capital costs of each energy type with technological change as well as with draw-downs of resources
- Is a partial equilibrium model in which energy stocks buffer imbalances between production and consumption and determine price changes
- Overrides the energy sector in the economic module unless the user chooses otherwise

The socio-political sub-module:

- Represents fiscal policy through taxing and spending decisions
- Shows six categories of government spending: military, health, education, R&D, foreign aid, and a residual category
- Represents changes in social conditions of individuals (like fertility rates or literacy levels), attitudes of individuals (such as the level of materialism/postmaterialism of a society from the World Values Survey), and the social organisation of people (such as the status of women)
- Represents the evolution of democracy
- Represents the prospects for state instability or failure

The international political sub-module:

- Traces changes in power balances across states and regions
- Allows exploration of changes in the level of interstate threat

The environmental module:

- Allows tracking of remaining resources of fossil fuels, of the area of forested land, of water usage, and of atmospheric carbon dioxide emissions
- Provides a display interface for the user that builds upon the Advanced Sustainability Analysis system of the Finland Futures Research Centre (FFRC), Kaivo-oja, Luukanen, and Malaska (2002)

The implicit technology module:

- Is distributed throughout the overall model
- Allows changes in assumptions about rates of technological advance in agriculture, energy, and the broader economy
- Explicitly represents the extent of electronic networking of individuals in societies
- Is tied to the governmental spending model with respect to R&D spending

3.3.2. IFs for TERRA

During the course of the TERRA project, a version of IFs was developed and elaborated under the name IFs for TERRA. It has been used for analysis across the three themes of TERRA and all of the focal points, producing several versions of a living document called "Integrated Sustainability Analysis."[14] The model will be freely available after the TERRA project and will constitute one of the legacies of the project for researchers and policy analysts.

During the course of the TERRA project many changes and extensions were made to create IFs for TERRA. With respect to the model itself they include elements tied to each focal point of TERRA:

- Representation of an ICT sector in addition to the earlier 5 sectors of the economic model.
- Representation of R&D among government expenditure categories.
- Addition of a basic representation of growth in electronic networking, as motivated by the original NEMO model.
- Addition of an educational sub model representing intake and graduation of students at primary, secondary, and tertiary levels of education.
- Revision and elaboration of the production function in the economic model to represent endogenously and explicitly contributions to multifactor productivity from human capital (education and literacy), social capital (economic liberalism), and natural capital (the price of energy).
- Wrapping of the basic goods and services market representation within a social accounting matrix so as to capture and allow analysis of financial flows among households (skilled and unskilled labour), firms, and governments, as well as financial flows among countries.
- Addition of an Advanced Sustainability Analysis (ASA) system using the formulations of the FFRC team and of Theme 3.

With respect to the database of the system (to be discussed in more detail below), the changes to IFs for TERRA include:

- Very substantial expansion of the database for all focal points of TERRA.
- Enhancement of built-in capabilities for cross-sectional and longitudinal analysis of data.
- Extension of capabilities for presentation of data (including mapping).

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[14] In developing such a scenario, we apparently share much of the intent of Raskin, et al. (2001; see Kemp-Benedict, Heaps, and Raskin 2002) and the Global Scenario Group (http://gsg.org) in their development of a Global Transition Scenario. The PoleStar system is a remarkable tool for integrated scenario analysis, sharing some of the characteristics of IFs (see http://www.seib.org/polestar).

- Improvement in processes for comparing historic data and the results of forecast runs across past year.

With respect to transparency and openness of the model:

- Improved documentation of the model, including the ability to look on-the-fly at causal diagrams, equations, and computer code behind each computed variable.
- Inclusion of discussion of dominant relations within documentation of each module of the system.

For most users of IFs for TERRA, the most obvious changes/improvements will be in the user interface and the ease of model use for scenario analysis. Among the changes there have been:

- The addition of specialised displays for multi-issue, country-specific reports, for the presentation of forecasts related to the key dimensions of the World Value Survey, for the preparation of Lorenz curves and calculation of Gini indices, for the Social Accounting Matrix, and for the Advanced Sustainability Analysis.
- The addition, with the support of Ronald Inglehart and the University of Michigan of a Guided Scenario Analysis capability that walks a user through the steps of scenario analysis.
- On the output side, Sergei Parinov assisted in the development of a sensitivity analysis structure.
- On the input side, the interface facilitates the iterative development of scenarios through use of a scenario tree structure as shown in Figure 2.7.[15] That tree structure distinguishes among key framing assumptions, policy interventions, and relationship parameters. The modelling system carries standard framing scenarios such as the four major scenario families of the Intergovernmental Panel on Climate Change (IPCC). This is the system that is being used for development of the global sustainability scenario—the three component parts of the total sustainability scenario (policy levers around human capital, growth/equity and environmental quality, respectively) are saved in scenario input files that can be retrieved into the tree structure for examination and alteration.

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[15] Robert Pestel identified the need for a "policy cockpit" to facilitate interaction with IFs. The scenario-tree interface is a first significant step towards creating such a cockpit. Ronald Inglehart has also urged the development of a more game-like interface for the IFs system; moreover, he has facilitated support for graduate assistance in development of such a system from the European Union Center at the University of Michigan (appreciation to the Associate Director, Daniela Gobetti, and to graduate student Ramandeep Arora). For many years, one of the most active users of IFs in the classroom has been Richard Chadwick at the University of Hawaii. He also long imbedded use of the model in Thomas Saaty's (1996) framework of hierarchical decision-making, and he advocated the more conscious inclusion of such an approach in the model's interface. The scenario interface is a step in that direction, as is the Guided Use feature that has been growing out of the support of Inglehart.

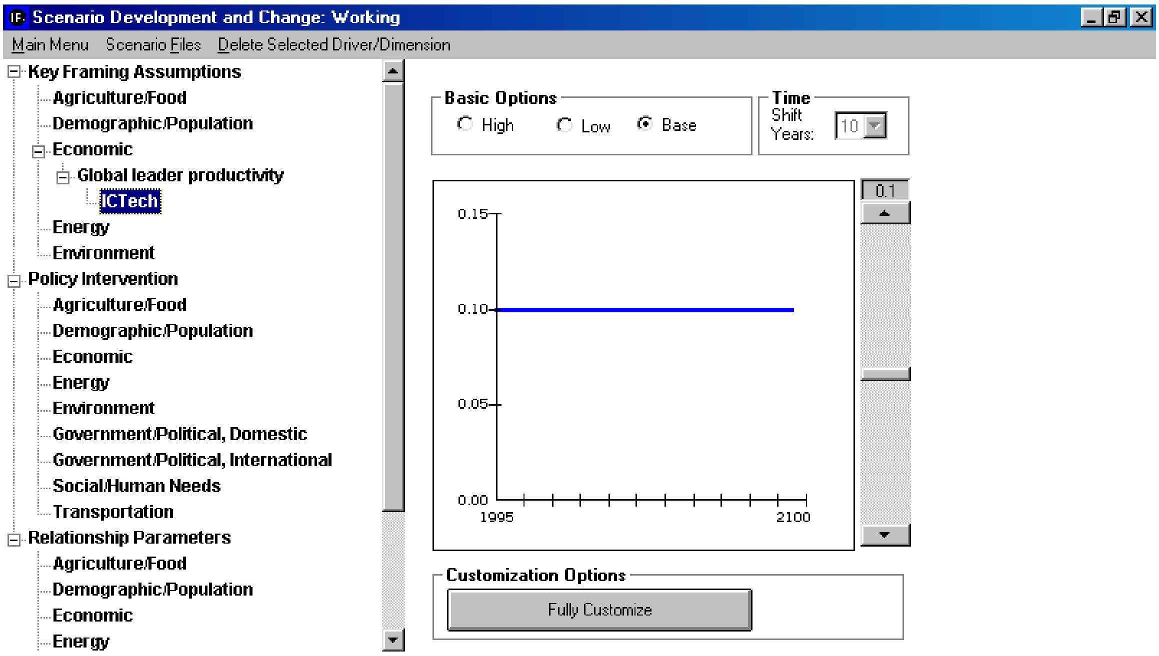

Figure 2.7 Policy Cockpit/Scenario Management System

3.3.3. Collective Modelling

The second integrative tool that the TERRA project identified from its beginning is collective modelling, namely an on-line system for collecting and integrating systems dynamics models. For description see Deliverable 5.2, "Initial working paper on sensitivity analysis and fast heuristics" by Sergei Parinov.

Although the basic system was developed further during the TERRA project and tested with several of the TERRA insight level, systems dynamics models, the reformulation of the project early in the second year interrupted the progress towards making the system a major component of the TERRA project. Nonetheless, the TERRA project demonstrated that collective modelling technology can facilitate the pooling of insight into complex global systems. The TERRA modelling team believes that this technology has not only contributed to model development within TERRA, but will live and prosper beyond the current project.

Figure 2.8 shows the on-line interface to the TERRA collective modelling interface (with URL http://terra21.socionet.ru). At that address, TERRA team members and others can download the *Insight for TERRA* paradigmatic-level model and work with it in their own Vensim environment (TERRA acquired and distributed 10 Vensim licenses throughout the team). At the time of the Denver modelling meeting, the modelling team also tested the general collective modelling technology through the addition to the system of model code developed by Mohammed Iran.

The plan for collective modelling was that when individuals would have changes to equations of the model that they wish to recommend for inclusion within the model, they could submit them via an e-mail message. The collective modelling interface has the capability to evaluate such recommendations technically for consistency with Vensim modelling standards. When submissions meet basic technical requirements, they would be added to the library of formulations for the model. Other user-developers of the model would then be able to download those formulations, experiment with them, and evaluate the merits of them.

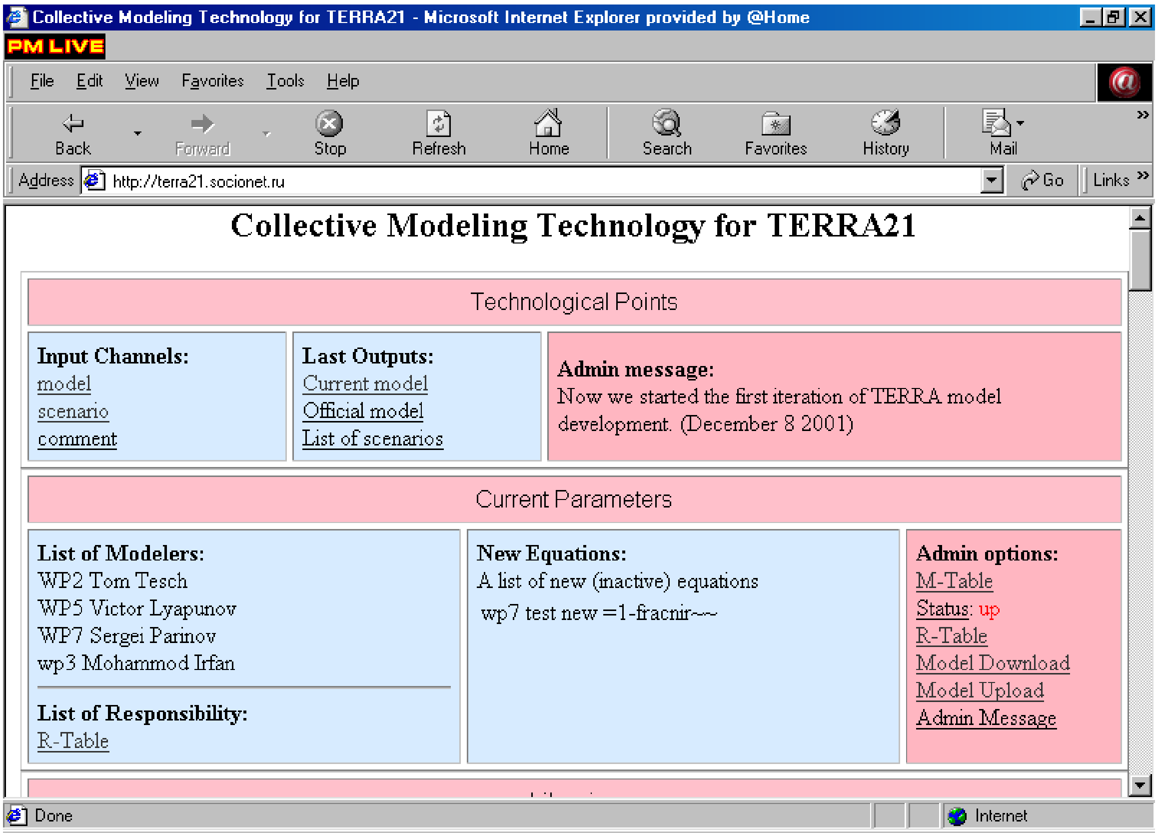

Figure 2.8 TERRA Collective Modelling Interface

3.4. DATA

In addition to the three types of models and tools, across the three levels of Figure 1.2, the TERRA tool kit obviously required an extensive database across the focal points of the project (see again Figure 1.1). Many members of the TERRA project contributed to the effort of building such a database. Most notable were

(1) The efforts of Ayres and Warr in obtaining and using very long term databases on energy and materials usage as well as production for selected countries in support of their analysis of exergy (see the reports on UNU materials data and on energy balances prepared for the original Work Package 4).

(2) The work of the FFRC team in obtaining data on labour, environmental inputs and outputs, and in support of their MAS measure (see the report in Task 14.5 on Database Development and Data Appreciation)

(3) The additional and integrative database work done by the Denver University team in connection with development of IFs for TERRA (see the reports on Data Needs, Sources, and Responsible Teams in the original Work Package 6 and the power point presentation on data developed for the February 2002 review, prior to project restructuring).

This section will comment a little more on the integrated database developed for the project. There were several general considerations that guided preparation of the integrated database:

1. Geographic coverage: 164 states (including Palestine)
2. Time span: 1960+ (as much of this period as possible; a few series were also added that began prior to 1960)
3. File format: Microsoft Access, exportable to MS Excel
4. Description, documentation: Data dictionary file in MS Access
5. Usage: augmented by analysis features of IFs for TERRA
6. Availability: Project Place in association with IFs for TERRA

The database was organised into categories that support the focal points of TERRA, while also being consistent with the organisation of the IFs for TERRA model. The number of series specific to each subcategory, as of early 2002, is shown in parentheses (the numbers of series, particularly in finance, have grown substantially since then):

1. Agriculture: consumption (2), price (1), production (11), trade (14)
2. Economic: aggregate (9), capital (1), finance (22), labour (15), price (2), production (15), trade (24)
3. Energy: consumption (10), price (3), production (13), resources (5), trade (4)
4. Environment: atmosphere (3), forest (1), land (6), recycling (3), hazardous waste (1), water (5)
5. Government: character (20), expenditure (11), finance (17), international (2), stability (19)
6. Information Communication Technology: computers (2), internet (5), investment (1), labour (2), newspapers (1), R&D (2), radio/television (3), telephone/fax (6), trade (4)
7. Population: fertility (4), labour (2), migration (7), mortality (3), size (3)
8. Science and Technology: articles (1), education (2), R&D (10)
9. Socio-political: education (18), equity (14), human needs (12), society (10)
10. Transportation: air (2), rail (2), road (2)
11. World Value Survey (85)

The data dictionary includes the following fields regularly, and some additional fields with less consistency:

1. Group
2. Subgroup
3. Variable Name
4. Definition
5. Units
6. Years
7. Source

The following is an example record with respect to the basic fields:

1. Science Technology
2. R&D

3. R&DtotPersonnel
4. Total personnel engaged in R&D
5. Millions
6. 1981-1999
7. OECD Science & Technology CD 2000

A number of specialised data sources were used for data that supported TERRA and was put in part into the integrated database, but that was more extensive than needed or desired in the integrated database:

Global Trade Analysis Project (Purdue). IO matrices, payments to labour, and much more for nearly 60 sectors and 70 countries/regions (release 5)

Full OECD Labour Statistics

Long series for MARGRET (energy, resources from IEA and USGS)

Extended World Value Survey data (Inglehart)

4. NEXT STEPS

The first chapter of this report outline the conceptual foundations for the tools and models within the TERRA project and also indicated an overall design for what most modelling team members considered an ideal integrated tool kit. Figure 3.1 reproduces the figure from that discussion.

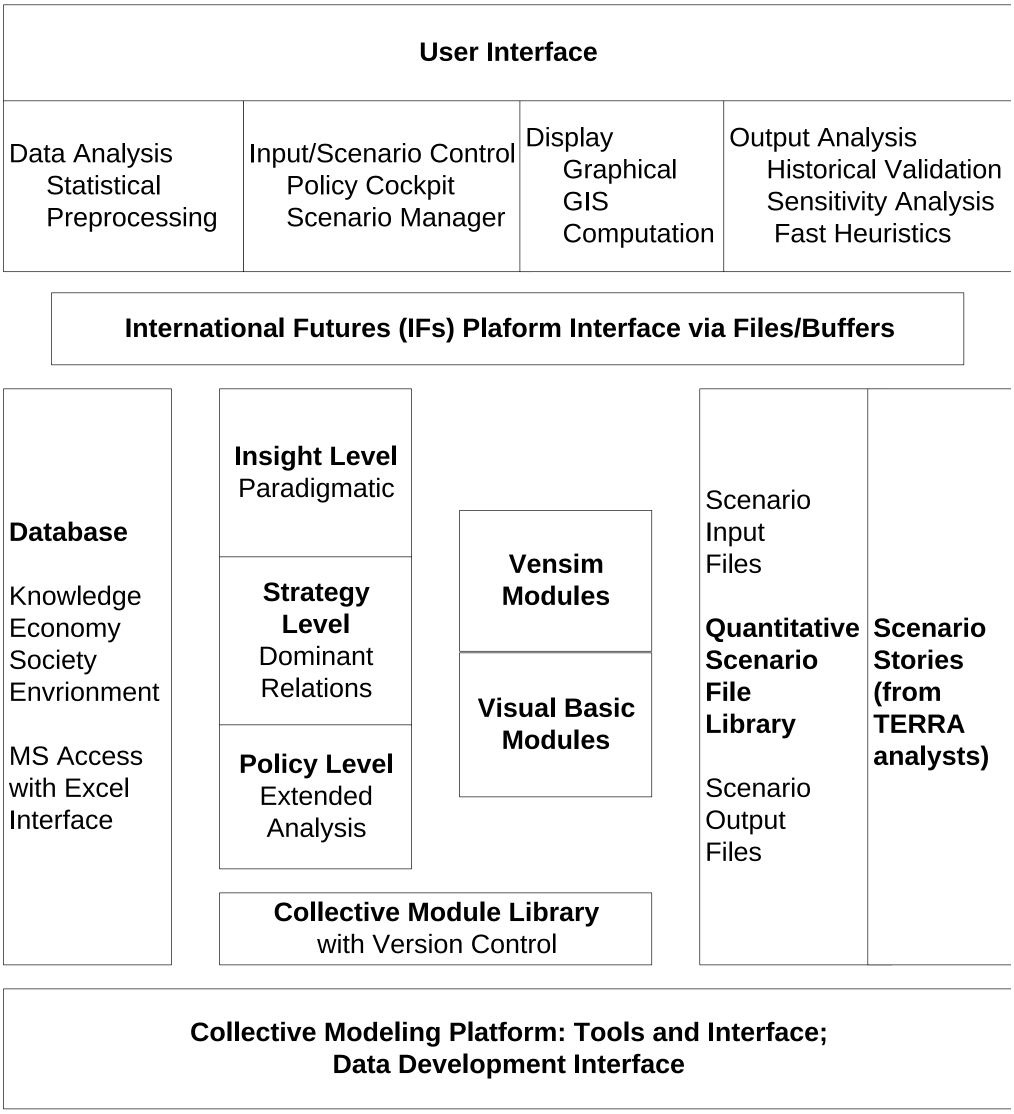

Figure 3.1 The Desired or Ideal Modelling System and Tool Kit

Although it was overly ambitious to believe that a three-year project with limited resources and a strong substantive agenda that required primary attention could bring the ideal into being, it was nonetheless certainly appropriate for the modelling team of TERRA to conceptualise such an ideal.

How well did the modelling team ultimately do in moving the conceptually integrated ideal towards a physically integrated, or at least modularly functioning (via mutually supporting elements) reality? Actually, quite well. As this document has indicated, the following were accomplished:

- The development of model elements at each of the three analytic levels and the bringing to bear of those models on the three themes (as discussed throughout this report).
- The use of Vensim and Visual Basic for the development of the modules, but without the desired integration of the two platforms (the Denver team has, however, recently completed a proof of concept of the integration of Vensim modules with IFs for TERRA).
- The development of a test library of Vensim modules within the collective modelling system
- The development of the extensive database for TERRA and the complete integration of that with IFs for TERRA.
- The completion of most user interface items (the primary exception being fast heuristics) within the IFs for TERRA system.

If the modelling team were able to build further, and most members hope that it can, these would be some of the priorities:

- The true integration of Vensim and Visual Basic model elements
- The linking of database and IFs for TERRA to the collective modelling system
- The migration of most modelling elements towards an actor-based focus to facilitate more concrete policy analysis (in early versions of NEMO this was discussed in terms of "communities of interest"; in recent versions of IFs for TERRA this has been emerging in terms of the actor-classes represented in the social accounting matrix framework).

In conclusion, the tools and modelling team of TERRA express the hope that their ideas, as well as the specific models and tools that they developed and the analyses they supported can be of use to others beyond the TERRA project.

SOURCES AND REFERENCES

Barabaśi, Albert-László. 2002. *Linked: The New Science of Networks*. Cambridge, Massachusetts: Perseus Books.

Directorate of Intelligence, Office of Transnational Issues, Strategic Assessments Group. 2001 (February). *The Global Economy in the Long Term*. Washington, D.C.: Office of Transnational Issues.

Hammond, Allen. 1998. *Which World? Scenarios for the 21st Century*. Washington, D.C.: Island Press.

Hughes, Barry B. 1999. *International Futures: Choices in the Face of Uncertainty*. Boulder, Co: Westview Press.

Kaivo-oja, Jari, Luukkanen, Jyrki and Malaska, Pentti (2001a) Advanced sustainability analysis. In: M.K. Tolba (Ed.) Our Fragile World. Challenges and Opportunities for Sustainable Development. Encyclopedia of Life Support Systems and Sustainable Development. Vol 2. Oxford: EOLSS Publishers Co. Ltd, 1529-1552.

Kaivo-oja, J., Luukkanen, J. and Malaska, P. (2001b). "Sustainability Evaluation Frameworks and Alternative Analytical Scenarios of National Economies. Population and Environment." *A Journal of Interdisciplinary Studies* 23:2, 193-215.

Kaivo-oja, Jari, Luukkanen, Jyrki and Malaska, Pentti. 2002. "Methodology for the Analysis of Critical Industrial Ecology Trends: An Advanced Sustainability Analysis of the Finnish Economy" *Futura*.

Kemp-Benedict, Eric, Charles Heaps, Paul Raskin. 2002 (March). Global Scenario Group Futures: Technical Notes. Boston: Stockholm Environmental Institute, Tellus Institute. PoleStar Series Report no. 9.

Malaska, P., Kaivo-oja, J. and Luukkanen, J. (1999). "Sustainability and Economic Growth: A Theoretical Framework and Empirical Demonstrations." Futu-publication 4/99. Finland Futures Research Centre. Turku School of Economics and Business Administration, Turku.

Mesarovic, M.D., D.L. McGinnis, and D.A. West. 1996. *Cybernetics of Global Change: Human Dimension and Managing of Complexity*. MOST Policy Paper 3, UNESCO, Paris, 1996.

Raskin, P., T. Banuri, G. Gallopín, P. Gutman, A. Hammond, R. Kates, and R. Swart. 2001. *Great Transition: The Promise and Lure of the Times Ahead*. Forthcoming (see http://www.gsg.org/Initiatives/BTC01/Data/BTC01_data.htm).

Rudman, Warren and Gary Hart. 1999. *The World Coming*. Washington, D.C.: The United States Commission on National Security/21st Century.

Saaty, Thomas L. 1996. The Analytic Network Process: Decision Making with Dependence and Feedback. Pittsburgh: RWS Publications.

TERRA (2001) Deliverable 7.1-3, "Prototypes for Integrated Model and Tool System"

TERRA (2002) Deliverable 15.5-3, "Tools and Models Living Document"