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# THE SHORT HISTORY AND THE PLAUSIBLE FUTURE OF WORLD MODELLING*

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This study summarises the methodological aspects of the most important computerised world models and describes their prospects for the near future. Throughout the three stages of the evolution of world modelling, the development of computer technology has had a definitive role, hence this study regards computer technology as a framework of world modelling. The first evolutionary stage is related to the spread of IBM computers at the beginning of the 1970s, its milestone being the model published in The Limits to Growth (Meadows et al. 1972). With the spread of desktop computers in the second stage, world models that could run on PCs appeared; the first one being MicroIFs (International Futures) in the second part of the 1980s. The third wave was generated by the proliferation of the Internet and the continuing acceleration of the processing speed of computers. Models have become downloadable, virtually simultaneous processing options enable multi- agent-based simulations. As a result of these, models can be extended with the analyses of dynamic and emergent phenomena. Recent methodological concepts and trends promise new theoretical synthesis of world modelling.

**Keywords:** world model, global model, futures studies, macroeconomy, research methodology, floating model

**JEL classification index**: C3, C53, C87, E17

## 1. INTRODUCTION

Numerical, computer-based world modelling dates from the start of the 70s to the mid-80s of the last century. The results of this glorious decade are well known among professionals and modellers, but neither the inexpert audience nor the students of the 21$^{st}$ century are generally aware of the findings and details of these models. Can this be explained by the fall of world modelling or is it simply a question of communication?

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These world models had several notable outcomes – the first warnings of global environmental and energy crises, scientific forecasts of overpopulation, the spread of new terminology (e.g. "sustainability"), etc. In spite of these echoes – except for some rare applications – world models got nipped behind the walls of academic institutions. The mainstream of publications, from scientific journals to daily papers, has dealt with the topic of globalisation over the last ten or twenty years.

The origins of world modelling and simulation were laid down three hundred years ago, with differential equations – needless to say, the term "world modelling" was not used at that time. Nowadays the term is rarely used in the above context, although the activities and aims behind the different labels are still similar: understanding the present and forecasting the future. The majority of world models are dynamic system simulation models, although input-output and mixed models exist, too. The estimated number of significant world models and their versions is above 50. This publication can only report on a fraction of those.

There is no explicitly elaborated definition of "world modelling"; terms and conventions were introduced by major publications, however. These provide a sufficient basis to see "world models" as simulating tools of multiple, humanity-related phenomena. Traditionally "multiplicity" refers to the fact that world models include at least 2–3 (problem) areas (i.e. economy, society, environment), while "relations to humanity" stands for processes or conditions in close interaction with either the whole of humanity, or only with a particular segment of it. Representations of world models are computer programmes and/or the output of these (tables, charts, etc.), of course the latter are further analysed and described. Besides publications, some world models are accessible online and the user can work with them directly.

There is no room to indicate all important types of world models[1] in the present paper, for example climatic world models (although the IMAGE model in subsection 3.3. does contain information on the climate system) or country-level models. This paper focuses on human-behaviour and environment-related (economy, society, politics, demography, energy, pollution, etc.) global, or regional world models.

## 2. THE FIRST HEROES OF WORLD MODELLING AND THEIR FOLLOWERS

Summarising the most important world models of the 70s, the aim of this section is to provide an introduction to the trend of methodological developments. The first phase of world modelling was initiated by the technological improvement of

[1] The list of most popular world-models can be found in the *Appendix*.

computers. In this part of the study, nine models are commented: WORLD2, WORLD3, WIM, SARUM, WIOM, RW–3 and RW–4, FUGI, GLOBUS, International Futures (version one).

**2.1. WORLD2 (1972)**

The first dynamic world model was developed by Jay Forrester at MIT (Massachusetts Institute of Technology), based on his previous efforts on system dynamics, industrial dynamics and urban dynamics. WORLD1 was a paper-and-pencil model of Forrester, its draft was created on a plane back from the meeting with the Club of Rome in Bern, in 1970. The origin of system dynamics dates back to World War II, when a team of researchers – among them Forrester himself – conducted research on the so-called "feedback control mechanism" in the "Servomechanism Laboratory". The language of system dynamics was DYNAMO, first published in 1959. WORLD2 – a real, system-dynamics-based, computerised world model – mapped associations between world population, resources, pollution, industrial production and food (Forrester 1971).

**2.2. WORLD3 (1972)**

The first publication of the Club of Rome, entitled "The Limits to Growth" (1972) contained the results of the simulation of the world using the system dynamics of WORLD2. The project was led by Dennis Meadows, a former PhD student of Forrester. The famous report was based on the WORLD2 methodology, but was more deeply elaborated. WORLD3 included 5 factors: population, food production, resource depletion, industrial output, and pollution. The historical base period was 1900–1970, the projection time horizon was 2100. The model introduced the term "carrying capacity" as a reference level of population and production. The conclusion of WORLD3 was similar to that of WORLD2.

"The Limits to Growth" was preceded by the "Predicament of Mankind" project in 1970, focusing on problems such as poverty, environment, loss of faith, urban sprawl, work insecurity, youth alienation, loss of values, inflation and was followed by "Toward Global Equilibrium" (1973), "Dynamics of Growth in a Finite World" (1974) and "Beyond the Limits" (1992) from Donella and Dennis Meadows et al. The tentative conclusion of WORLD3 in their own words was "imperfect, oversimplified, and unfinished" (Meadows et al. 1972). The main reason for the harsh criticism was the fact that WORLD3 handled the globe as a single unit.

### 2.3. WIM (1974)

Compared to WORLD3, World Integrated Model, which appeared in a publication entitled *Mankind at the Turning Point* (Mesarovic – Pestel 1974), is significantly upgraded, because Mihajlo Mesarovic and Eduard Pestel used regional data for their computations. Their historical base period was 1950–1975, the projection time horizon was 2025. World Integrated Model (WIM) first used 10, then 14 geographical regions, 17 scenarios were analysed, and its methodology was based on Mesarovic's "multilevel hierarchical systems theory". WIM put emphasis on regional interdependence and policy, hence it provided a more complex view of the world. From an economist's point of view, WIM was a collection of regional economic models. The resulting mathematical model is quite large compared to previous ones, WORLD1 contains only 40 equations, WORLD3 about 200, while WIM contains over 100,000 (Cole 1978).

WIM models the dynamics of the production and demand of a selected number of commodities: food, energy and capital goods. The core of WIM's regional model was an economic sub-model. The dynamics correlated with production, consumption, and particularly the trade of the commodities which govern the long-term economic behaviours. WIM applied a highly interactive software package that greatly enhanced the model's ability to test assumptions and scenarios.

### 2.4. SARUM (1975)

Systems Analysis Research Unit Model (SARUM), developed by Peter C. Roberts in the United Kingdom has a couple of upgraded versions. The aim of SARUM as a "General-Purpose Model" (Clark et al. 1977) was to simulate world economy, with emphasis on the increasing costs of natural resources. SARUM suggested the same conclusions as the Meadows team. Most of SARUM's conclusions remain classified, because of the UK's vulnerability to disruptions in international trade.

Half a decade later, SARUM was substantially revised through Richard W. Chadwick's direction of the G-MAPP Project. The so-called "Richardson process" – which is a relatively simple mathematical model to describe the escalation of wars – is also linked to this world model (Chadwick 1986; Vág 1987).

### 2.5. WIOM (1976–1984)

World Input–Output Model (WIOM) or "Leontief model" was published in a volume entitled *The Future of the World Economy* (Leontief et al. 1977). The sub-systems of the model are economy, agriculture, raw materials, government data, international markets, trade, etc. The model included 15 regions and its forecasting horizon was 2000. Leontief's WIOM explicitly uses feedback loops linking outputs from his I–O matrix to inputs to assess medium-term trends.

### 2.6. RW–3 and RW–4 or IWM (1977)

Regional World–3 was developed by Fred Kile and Arnold Rabehl in the middle of the 70s as a stepping-stone for their next models. RW–3 is more simple than WIM and International Futures, but contains some important additional modules, such as food production and consumption, development of technology, macroeconomy, trade, demography and food aids. RW–3 includes 26 countries and groups of countries (Kile – Rabehl 1977).

Presented in 1977, Regional World–4 is characterised by a more detailed grouping of countries (24 countries and groups) than RW–3, and includes such new areas as governmental expenditures, energy, labour force and wealth indicators (Kile – Rabehl 1980).

### 2.7. FUGI (1977–1994)

Future of Global Interdependence (FUGI) was led by Yoichi Kaya and Onishi Akira. FUGI was first presented in Vienna at an IIASA conference in 1977. The sub-systems of FUGI are economy, agriculture, raw materials, government data, international markets, trade, international relations, conflicts, etc. The number of regions was between 15 and 62 depending on the model version. Version four consisted of 30,000 equations. FUGI model seven classified the world into 80/180 countries/regions within the frames of FGMS (FUGI Global Modelling System) research. FUGI employed mixed methodology: system dynamics, input–output model and econometrics. Unlike most of the other world models FUGI had a linear programming module. The projection horizon was 1991–2000 (Onishi 1977; 1992).

### 2.8. GLOBUS (1981–1988)

Generating Long-term Options by Using Simulation (GLOBUS) is an advanced model, developed at the Wissenschaftszentrum, Berlin, Germany. From a methodological point of view GLOBUS is an econometric model with great emphasis on political issues. The political dimension is mirrored e.g. by estimates of strength of political protest. Fields analysed include demography, economy, raw materials, agriculture, government data, international markets, trade, international relations. The number of regions is 5 in the 1981 version, and 25 in the 1983 one. The model's forecasting horizon is 2015 (Bremer 1981; 1987).

**2.9. International Futures (1982)**

International Futures (IF), developed by Barry Hughes, evolved from 1980 through four generations. The first generation was a little more than an upgrade of Mesarovic and Pestel's WIM (Barry Hughes had contributed to the WIM development project). International Futures also drew on Leontief's I–O model (Leontief et al. 1977), the Bariloche Foundation's world model (Herrera et al. 1976), and the Systems Analysis Research Unit Model. Although IF was primarily used by students, it had policy analysis capabilities, too. International Futures represents the dynamics and interaction of demographic, food, energy, economic, environmental, and socio-political systems. The division of the world into 17 countries and regional groups allows the researcher to discover the interactions and differences between these regions and countries. IF is capable to treat "if–then" alternative statements about the future.

Hughes summarises the philosophy of IF as "We will never fully anticipate [our choices'] consequences for ourselves or others. We will act in the face of uncertainty. Yet we will make choices; collectively we will continue to reshape the world. What will be the future of human environmental, economic, and socio-political systems in the 21st century? … No one knows. We cannot know the future, but it is essential to act in the face of that uncertainty" (Hughes 1980). The following generations of IF are presented in the next chapter.

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The first world models drew the attention of the public to so-called world problems. Except for the Leontief model (WIOM), all were based on system dynamics developed by Jay Forrester. The spreading of system dynamics as a modelling concept and the increase of the number of functions and variables within the models were enabled by the rise of computer technology. Nevertheless, the knowledge base of the first world models is really small compared to those of the end of the century. First world models contain the sprout of interactivity by allowing developers to adjust initial parameters of the models, as means to run different scenarios. In this period, world models were accessible neither by the research community nor by the large audience.

## 3. TODAY'S WORLD MODELS

Paving the way for the new generation of world models, the last decade was determined by the spread of personal computers and the possibility of running world models on PCs. Parallel to this, models became more and more advanced, regionally detailed and new modules were introduced. world models clustered to this group are International Futures versions 2–4, IMAGE, Globesight, TERRA and GEM–E3.

### 3.1. Updates of the traditional world models

#### *3.1.1. International Futures (1985–2000)*

The second generation of IF, the first global model that could run on PC, can be regarded as a simplified version of first-generation IF since it had no regional or country differentiation. The third generation (1993), however, became a full-scale PC world model. It also improved the representations of energy and food systems, while demographic, new socio-political and environmental content were added. This version of IF adopted the economic model of GLOBUS.

Interest in the model was increasing, demand from important business and research organisations triggered further upgrades, which finally resulted in the birth of the fourth generation of IF in 2000. Examples for application are an alliance established with the World Values Survey (Inglehart 1997) and a project named TERRA, funded by the EC.

International Futures, a macro-level world model without decisions and agents, produces forecasts by time-series and functions. Subjects are analysed at global, regional and national level. IF cannot be used for demonstrating complex adaptive systems, since there is no emergence and no generative modelling included. The model's utility is found in experiments that begin by saying, "if the world works as assumed in this model, then what would happen if I change some specific relationships or intervene with specific policies" (Chadwick 2000). Another concern is that the multitude of parameters and variables may lead to difficulties in identifying factors driving outcomes. This can cause problems in understanding policy projections. The late version of IF has the following detailed sub-modules: economy, agricultural energy, socio-politics, international politics, environment and implicit technology. The student version of IF is downloadable from the Internet.

*3.1.2. Globesight*

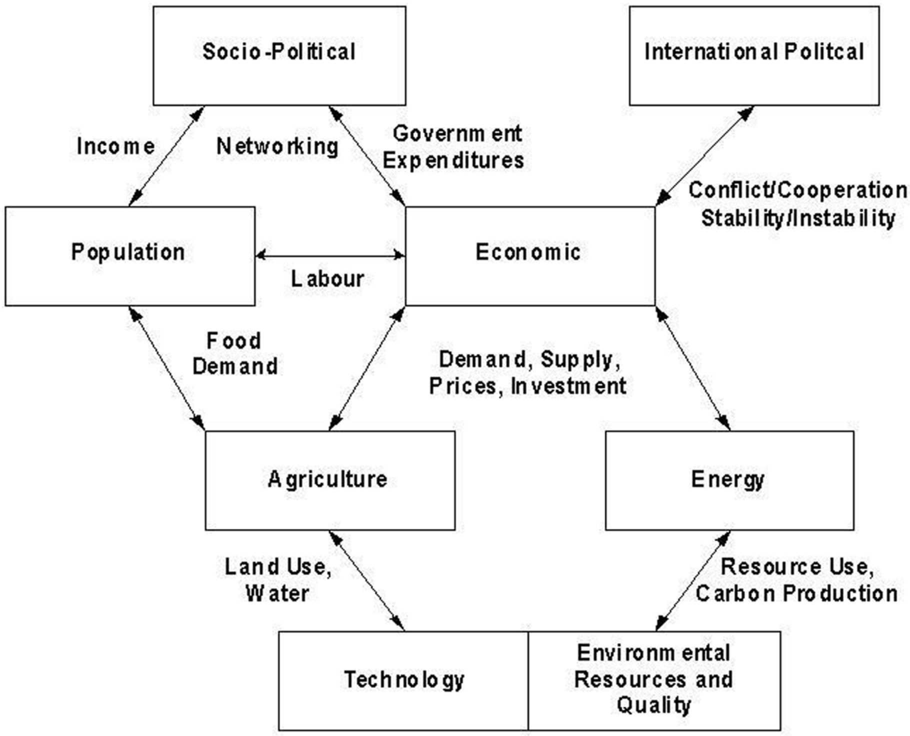
Mesarovic's WIM seems to be further developed in two major directions – a work for the military intelligence community within the Pentagon, and an international education programme (GENIE) sponsored by the UNESCO with a core model. Today, the project's portal labels GLOBESIGHT as a "Reasoning Support Tool" which has been built with the philosophical and the methodological foundation described in Mesarovic et al. (1996). The tool 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. In this way the scenario analysis approach can be used to look into the future.

Globesight's knowledge base contains both quantitative and qualitative data at country, region and world levels, describing geographical, cultural and socio-economic characteristics. The model's database consists of data from 196 countries, geographically or economically contiguous regions that are aggregated from the countries (some aggregations used, for example, 21 regions, five continents, developing countries, countries in transition, and developed countries).

Functionality deals with three issues: input, output, and process. Broadly, input consists of data-import and model-management utilities. Output formats include multi-axis graphs with an interface to change different types of plots. In addition, a geographical information system (GIS) interface is available; features such as rivers could be overlaid on the graphs and standard geographic views are included. By using multiple interpolation methods, an interpolation routine to shape key inputs (such as rate of economic growth, for example) is available. Goal seeking, wherein a desired goal (e.g. emission target) with a single input (e.g. economic growth) has been implemented (Mesarovic et al. 1996; Sreenath 1999).

*3.1.3. TERRA*

TERRA is an EU/IST-funded project, employing Barry Hughes' IF and improving on it. The resulting model is a recursive system that can run without intervention from its initial year (2000). *Figure 1* shows the major conceptual blocks of TERRA, adapted from the IF system. The elements of the technological and environmental blocks are scattered throughout the model. TERRA enhances the original model by an improved representation of economic sectors, updated IO matrices and Social Accounting Matrix formulations for extended environmental im-




*Source*: Hughes (2003).

*Figure 1.* An overview of International Futures (IF) for TERRA

pact representation that draw upon the Advanced Sustainability Analysis framework of the Finland Futures Research Center (Kaivo-oja et al. 2002, IF homepage; TERRA homepage 2003).

### 3.2. Macroeconometric models

While world models introduced in the previous sections deal with different aspects of the modelled countries' activities and behaviour (like environment, energy, natural resources, demography), macroeconomic models focus principally on economic behaviour. In spite of this, macroeconomic models may still be treated as world models as the modelling methodology applied is similar to that of other world models (i.e. variable-based statistics and time-series, functions, equations and specific simulation dynamics); the behaviour of regions, countries, subcountries is studied by both kinds of models (macroeconomic models have organisational agents and households as well), and finally, the developers of macroeconomic models themselves call their products "world models".

Economic policy scenario analyses and macroeconomic forecasts constitute significant elements of macroeconometric multi-country models of the Commission of the European Union (Roeger – Veld 1997), the Economic Outlook of the OECD (1988) and the World Economic Outlook of the International Monetary Fund. Academics and research institutes, a number of central banks, the European System of Central Banks (Henry 1999) and the Japanese Economic Planning Agency (1995) have also applied macroeconometric multi-country models in their analyses. In this section of the study it is feasible to briefly present five macroeconometric models, G–Cubed Model, NIGEM, MULITMOD, Small Global Forecasting and GEM-E3. The author's choice was motivated by the fact that the documentation of these models is not only accessible but also accurate.

#### *3.2.1. G–Cubed Model*

G–Cubed Model is a wide-ranging, multi-sector, multi-country, general equilibrium world economic model suitable for modelling the effects of international trade policy and financial flows. The model has been used to simulate a variety of topics, like tax policies, trade liberalisation, macroeconomic policies and greenhouse gas emission policies. The model's main features are the following: (1) G–Cubed is disaggregated into eight geographic regions; (2) the production, consumption and international trade of each region is disaggregated into twelve sectors; (3) the model contains the complete specification of the demand and supply sides of each economy; and (4) full integration of real and financial markets; (5) the complete intertemporal accounting linking stocks and flows of both real and financial assets; (6) the imposition of all intertemporal budget constraints on agents and countries; (7) short-run behaviour is a weighted average of neoclassical optimisation and liquidity-constrained behaviour; (8) full short- and long-run macroeconomic closure around a long-run Solow/Swan neoclassical growth model; (9) solved at an annual frequency for a full rational expectation equilibrium out to 2050 or beyond (McKibbin – Wilcoxen 1998).

#### *3.2.2. NIGEM (1995)*

National Institute Global Econometric Model was developed by the British NIESR (National Institute of Economic and Social Research). NIGEM is an econometric model to simulate and forecast national economic behaviour of households, companies and the government, and also the impacts of different policies. NIGEM can be used both for countries and group of countries, since sub-models are interlinked consistently. The structure of the model resembles IMF's MULTIMOD model, although NIGEM contains more estimated parameters. Not only can NIGEM be used to carry out the extensive analysis of world trade, but it is also commonly used to analyse issues such as the evolution of national income, the effect of government deficit and the role of monetary policy (NIGEM Homepage).

The structure of the model reflects the neo-Keynesian view of its users. Besides the demand–supply side it also describes the monetary–financial sector. Typically, all developed economies are described with the same structure. Local differences are only mirrored by the differently estimated parameters and not by the different structures (Jakab – Kovács 2002).

#### *3.2.3. MULTIMOD (1988)*

MULTI-region econometric MODel was developed to analyse the macroeconomic impacts of the policies of industrial countries on world economy. The model has been extended in a number of directions, primarily with the purpose of increasing its usefulness in assisting with the IMF's multilateral examination of the policies of its member states (Masson et al. 1988). The latest version is identified as MULTIMOD Mark III.

MULTIMOD III has first of all been designed to study the short-run and medium-run consequences of alternative monetary and fiscal policies, as well as the transmission of shocks across countries. The basic Mark III model includes country sub-models for each of the seven largest industrial countries and an aggregate grouping of 14 smaller industrial countries. The remaining countries of the world are then aggregated into two separate blocks identified as developing and transition economies. The extended versions of MULTIMOD include separate submodels for many of the smaller industrialised countries, and research has been initiated to expand the analysis of developing and transition economies as well. The MULTIMOD modelling system includes a well-defined steady-state analogue model for each country and for the world economy as a whole. These models have two key functions. First, they are used to create terminal conditions for the dynamic models. Second, they can be used to study the long-run effects of shocks that have permanent consequences for saving, capital formation, output, real exchange rates, real interest rates, etc.

The basic structure of MULTIMOD is simple enough, so it is easy to estimate additional country models for the smaller industrial economies. Despite the focus on medium- and long-run properties, the model also exhibits important Keynesian, short-run dynamic that results from significant inertia in the inflation process. MULTIMOD Mark III features a non-linear relationship between unemployment and inflation that reflects short-run capacity constraints and insider-outsider influences on wages. The asymmetric property of the Phillips curve provides a fundamental role for stabilisation policies that is absent from linear models of the business cycle. The model assumes that behaviour is completely forward-looking in asset markets and partially forward-looking in goods markets. It is also possible to study the effects of shocks under alternative assumptions about expectations formation and the degree of policy credibility. The model is solved with simulation algorithms that have been designed specifically for such systems of equations.

MULTIMOD has not been designed to be a forecasting tool. The baseline corresponds to the medium-term World Economic Outlook projections, which reflect the detailed knowledge and judgements of the IMF's country economists. These medium-term projections are extended into a model-consistent balanced growth path where the real interest rate is greater than the world real growth rate (Laxton et al. 1998).

#### *3.2.4. Small Global Forecasting*

The main objective of Small Global Forecasting model is the production of globally consistent short-term forecasts of the major aggregates for the three main OECD economic regions, the United States, the Euro area, and Japan. The rest of the world is modelled as a fourth composite region. The variables in focus – including output, inflation, the trade balance, and import prices – are driven by world demand, exchange rates, monetary and fiscal policy. The projections from the model are used as a starting point to support the early stages of OECD's forecasting.

The model focuses on the transmission of influences between regions and the impact of global linkages in particular. The three regional models are linked directly via trade, interest rates, and exchange rates, but two additional linkages are also incorporated: (1) output and inflation in the rest of the world depend on developments in the three main regions and the feedback on them through trade equations; (2) commodity prices are endogenous and depend on world output and inflation. Both interlinkages provide additional cross-region channels through which shocks are propagated.

The model may be characterised as a demand-side model. Output is based on an IS-style relationship, although it is split into domestic demand and net export components. Potential output is assumed to be exogenous, and the model can therefore be written in terms of an output gap. In other words, the model explains why growth may differ from the potential growth rate but does not attempt to explain changes in potential growth. Given the model's primary roles of short-term forecasting and analysis of global linkages, this solution seems to be a reasonable simplification. However, it has a limited ability to analyse the impact of supply-side factors that may be expected to change potential output (Rae – Turner 2001).

#### *3.2.5. GEM–E3*

The General Equilibrium Model for Energy–Economy–Environment interactions is a European project, with a group of participants, led by P. Capros from the National Technical University of Athens. The model is being used to evaluate policy issues for the European Commission. Applications of the model are being carried out for several Directorate Generals of the EC (economic affairs, competition, environment, taxation, research). At present, version 2.0 is operational for EU–15, while further developments are under way.

GEM–E3 is an applied general equilibrium model for EU member states, taken individually or as a whole, which provides details on the macroeconomy and its interaction with the environment and the energy system. It is an empirical, large-scale model, written entirely in structural form. The model computes the equilibrium prices of goods, services, labour and capital that simultaneously clear all markets under the Walras concept.

GEM–E3 is a multi-country model linking countries through endogenous trade of goods and services, and includes multiple industrial sectors. The model is dynamic, recursive over time, involving dynamics of capital accumulations and technology progress, stock and flow relationships, and backward looking expectations (Capros 2002).

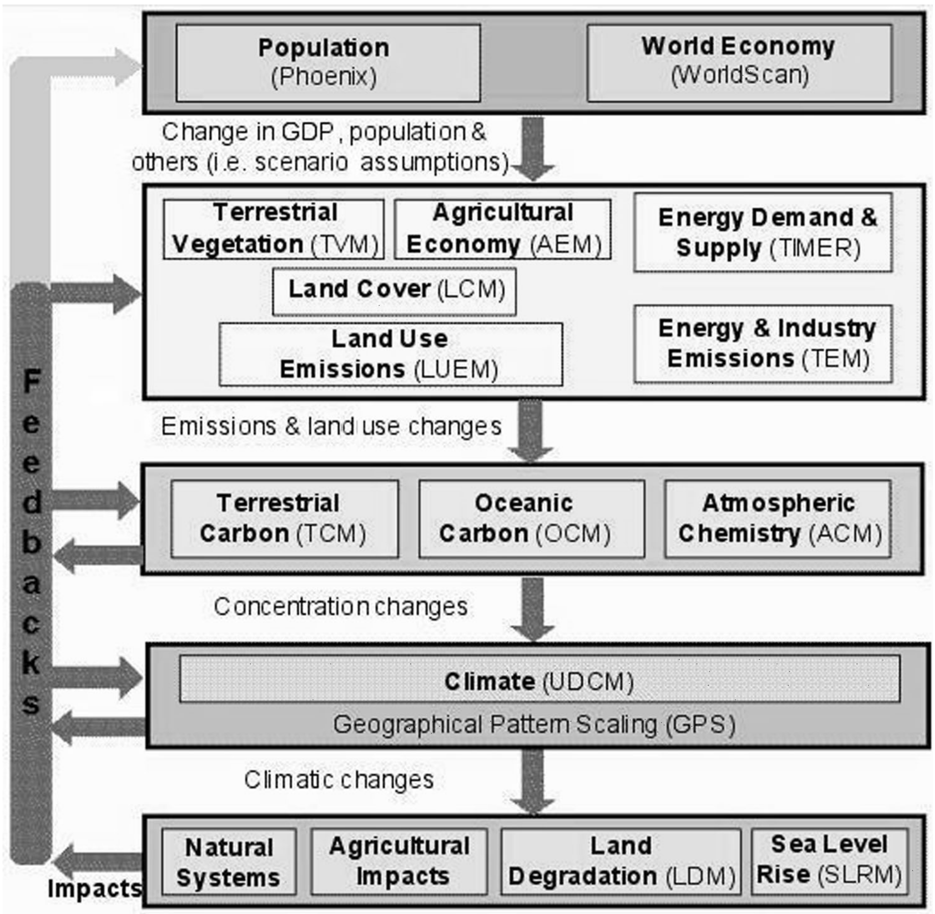
### 3.3. Highly integrated world models[2]

By the end of the 20$^{th}$ century models became highly integrated and extended to analyse new, emergent phenomena. Each of these models puts great emphasis on a scenario that is treated as a part of the methodological framework of that particular world model. Consequently, pure methodology becomes closely interlinked with both the concepts behind the model and the expected results.

2 The addresses of referred homepages can be found among *References* at the end of the study.

*3.3.1. IMAGE (1994)*

Integrated Model to Assess the Global Environment was presented in the book IMAGE 2.0 (Alcamo 1994), the last updates are accessible on the website of the Dutch National Institute of Public Health and Environment. IMAGE 2.2 is a multi-disciplinary, integrated model designed to simulate the dynamics of the global society–biosphere–climate system. *Figure 2* summarises the sub- models of IMAGE 2.2.




*Source:* IMAGE 2.2. homepage.

*Figure 2.* Models used for the IMAGE 2.2 scenarios

The objectives of the model are twofold. It is aimed firstly at investigating linkages and feedbacks in the system, and secondly at evaluating consequences of climate policies. Dynamic calculations are performed till the year 2100, with a spatial scale ranging from grid (0.5 × 0.5 degrees latitude–longitude) to world and regional level, depending on the particular sub-model. The model consists of three, fully linked sub-systems: (1) Energy–Industry; (2) Terrestrial Environment; and (3) Atmosphere–Ocean.

The Energy–Industry Model computes the emissions of greenhouse gases in 13 world regions as a function of energy consumption and industrial production. Energy consumption is derived from various economic and demographic driving forces. The Terrestrial Environment Model simulates the changes in global land cover on a grid scale based on climatic and economic factors, and the flux of $CO_2$ and other greenhouse gases to the atmosphere. The Atmosphere–Ocean Model computes the build-up of greenhouse gases in the atmosphere and the resulting zonal average temperature and precipitation patterns.

The fully linked model has been tested against data from 1970 to 1990. After calibration the model could reproduce the following observable trends: (1) regional energy consumption and energy-related emissions; (2) terrestrial flux of $CO_2$ and emissions of greenhouse gases; (3) concentrations of greenhouse gases in the atmosphere; and (4) transformation of land cover. (5) The model can also simulate long-term zonal average surface and vertical temperatures.

Four standard scenarios are included. These scenarios, computed with IMAGE 2.0, are presented for selected aspects of the society–biosphere–climate system including primary energy consumption, emissions of various greenhouse gases, atmospheric concentrations of gases, temperature, precipitation, land cover and other indicators (Alcamo 1994, IMAGE homepage 2003).

#### *3.3.2. GEO–3*

GEO–3 is a project sponsored by the United Nations Environment Programme. Global Environmental Outlook (GEO) is not a single world model, but rather the compilation of simulation processes executed with a range of analytical tools, in consultation with experts. The GEO–3 project employed AIM (Asian Pacific Integrated Model), GLOBIO (Global Methodology for Mapping Human Impacts on the Biosphere), PoleStar (a software for sustainability studies developed by the Stockholm Environment Institute), WAterGAP 2.1 model (Water Global Assessment and Prognosis, developed by the Center for Environmental Systems Research, University of Kassel, Germany), and IMAGE 2.2.

### 3.4. New simulation packages

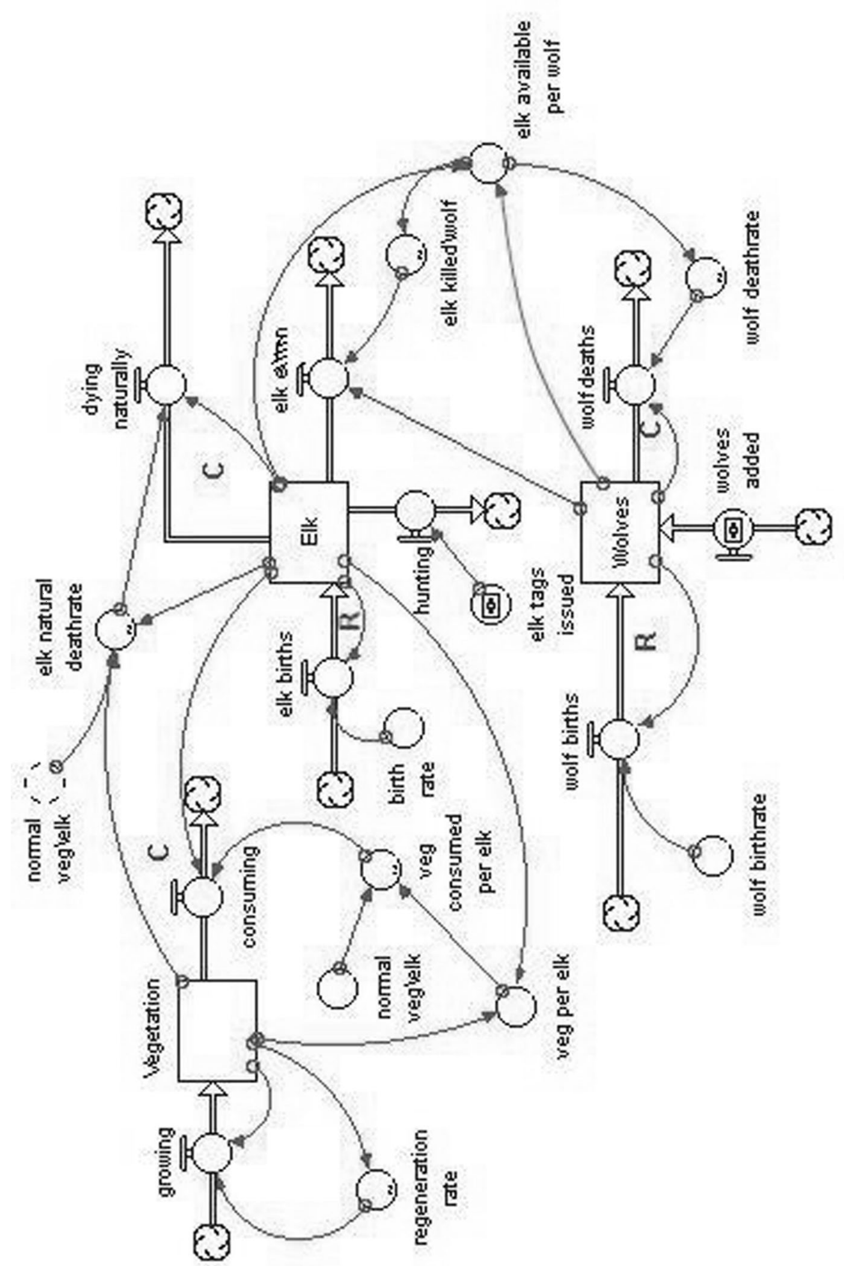
Compared to the first generation of world models, today's macroeconomic and world models are significantly more flexible. New approaches and methods have been appearing, algorithms used have become more and more advanced, and the knowledge bases have been expanding notably. Additionally, the curiosity of researchers has also broadened: ecology, environment, climate change, politics became integrated into world models. Parallel to these innovations, new simulation packages and other tools have been released to facilitate world modelling and forecasting. Moreover, multi-agent models (which help simulating emergent phenomena and interlink micro and macro levels) have been spreading, together with the appearance of free access models and online applications. Although the number of widely used packages is much higher, this study will introduce four simulation packages: STELLA, NetLogo, CORMAS and WiF. Further details about methods, softwares and other related issues can be found in the excellent book of Gilbert and Troitzsch (1999).

#### *3.4.1. STELLA*

STELLA is a widely used simulation software in the research industry, education and business. It can be best identified as a queuing/system-dynamics model for discrete event simulation. STELLA and the associated framework (Systems Thinking) enable professionals in science and research to represent key social processes, ecosystems and other simulations operationally, and share insights and results. The software and its framework are most widely applied to economics, mathematics, life sciences, physical sciences, and social sciences. *Figure 3* shows a simulation flowchart of a simple ecological model, downloaded from STELLA homepage. The flowchart is presented to show the symbols and illustrate the flexible visualisation of the simulation software.

#### *3.4.2. NetLogo*

NetLogo is a programmable modelling environment for simulating natural and social phenomena, developed at Northwestern University, USA. It is particularly well-suited for modelling complex systems developing over time. Modellers can give instructions to hundreds or thousands of independent "agents" all operating in parallel. This makes possible to explore the connection between the micro-level behaviour of individuals and the macro-level patterns that emerge from the interaction of many individuals.




*Source*: STELLA homepage.

*Figure 3.* A simulation flowchart of a simple ecosystem with STELLA

NetLogo lets students open simulations and “play” with them, exploring their behaviour under various conditions. It is also an “authoring tool” which enables students, teachers and curriculum developers to create their own models. NetLogo is simple enough that students and teachers can easily run simulations or even build their own. Furthermore, it is advanced enough to serve as a powerful tool for researchers in many fields (Wilensky 1999). NetLogo is downloadable from the project’s portal.

*3.4.3. CORMAS*

CORMAS is devoted to the applied modelling of the relationships between societies and their environment. The team of developers are associated with the “Renewable Resources and Viability” programme (TERA department) of CIRAD, France. The project focuses on developing multi–agent systems about integrated natural resources management. The computer tool, which is an agent-based simulation framework, may be downloaded from the Internet portal of CORMAS free of charge. The user will also be able to access application examples (with a models library) and publications.

*3.4.4. WiF*

World in Figures is an online knowledge base with direct access to a great amount of numerical data, developed by a project led by the author of the present study. The dissemination service is extended with a flexible statistical data analyser and some online models. The project’s portal is a gateway to an integrated statistical database containing global, country and sub-country level data (Vág 2003; Vág – Kuti 2002). World in Figures shows signs of integrating “traditional”, variable-based analyses with novel, advanced tools like multi-agent and queuing models. Additionally, it tends to realise one possible form of floating modelling philosophy.

### 3.5. Summary of today’s world models

Today’s world models are colourful and methodologically innovative. The traditional modelling philosophy has been extended with additional concepts, higher level of integration and new application packages. Meanwhile, the scope of simulated phenomena have also been widened or changed, for example by linking micro and macro levels of societies and economies. Mainstream macroeconomic modelling also became widely used in world modelling. Nowadays, world models are running on desktop computers, some of them are downloadable from the Internet, some others – not the complicated ones – are running online. A good indicator of methodological innovation is the appearance of multi-agent models, which do not include data (i.e. time-series) and the model structures are set up by the user. Anyway, the methodological innovations and the accelerating computer processors led to brand new world model philosophies.

## 4. NEW CONCEPTS OF WORLD MODELLING METHODOLOGY AND PROSPECTS FOR THE FUTURE

The improvement of world modelling methodology is largely motivated – besides the dramatic effect of the development of computer technology – by new concepts and approaches. The results of artificial intelligence research (i.e. evolutionary algorithms) and even philosophical and psychological theories support new world modelling practice. Advances in cognitive science, challenges of the complexity paradigm, the layering concept and "zooming" are all good examples for researchers' interest. Otherwise, the idea of "new generation of global modelling tools" in a specific context was first expressed by Hoffman. He argues that the use of global modelling tools is a means of expanding our collective capacity for perception. He proposes that "the establishment of a process consisting of the design and use of modelling tools [serves] to further the explication and communication of understanding, thereby facilitating both individual and societal action" (Hoffman 1993: 1).

The emerging major challenges for world modelling methodologies of the next decades can be summarised as (1) the application of new software packages and algorithms; (2) an increased level of model complexity; (3) the processing of qualitative and narrative information; (4) the usage of huge, integrated databases; (5) the development of online and downloadable models; (6) the management of projects in global networks; (7) the high level of interactivity; and (8) "floating" modelling philosophy. Each of these challenges will be explained in the following subsections.

### 4.1. New software packages and algorithms

Methodology-oriented new paradigms have been appearing since the 1980s and the 1990s, among them, for example, non-linear modelling approaches, analysis of dynamic phenomena, chaos researches, multi-agent methods and other evolutionary algorithms, pattern recognition and event data analysis. In short, the tools of artificial intelligence have been employed. These methodological concepts and algorithms have been turned into practice in social sciences since the middle of the 1990s and it is plausible that they will be widely used in future world models. The "new" methods will be integrated with "traditional" ones (like system dynamics, differential equations, time-series analysis, multivariate and clustering methods, etc.) into advanced software packages. This kind of integration will contribute both to the improved forecasting value and the increased accuracy of simulation processes.

### 4.2. Increased level of model complexity

Nowadays, the term "complexity" is one of the most popular expressions in science. In this context the meaning of the term seems relatively simple at the first sight – future world models will work with much more data than the preceding ones and the inventory of methods will also be more advanced. This will result in an increased level of model complexity. Emphasis will be put on the in-depth analyses of sectoral and/or regional problems, where approaches of different disciplines (i.e. ecology, socio-economic research, climate research) will be integrated in joint projects. This attribute of future world models closely interlinks with the "floating" modelling concept.

### 4.3. Processing qualitative and narrative information

One of the most frequent criticism of world models refer to the fact that they fail to integrate qualitative information. This fact can be partially explained by the traditional opposition and debate between qualitative and quantitative methodologists. New research and analysis methods focus on the options of transforming qualitative data into quantitative and *vice versa*. Computerised conversions and extractions, text-mining and automatic report generating opportunities are expected to significantly improve the efficiency of world models.

Text processing (i.e. automated translation) is an old problem of software developers and linguistics. The novel tools of artificial intelligence may contribute to the extraction of valuable data from narrative information. This approach has strong associations with the qualitative–quantitative conversion, having a definite potential in creating the link between "subjective" and "objective" information.

### 4.4. Usage of integrated databases

Data owners, public organisations and researchers have recognised the need for integrating statistical databases. For example, a great number of EC funds indicate this expectation of European societies. In early world models the emphasis was on economy. Later, the weight of politics, sociological factors and human values became more significant. Nowadays models are further extended with ecology, sectoral models and multi-level models, leading to a further decrease in the level of aggregation. From this aspect the usage of huge, integrated databases supports the complexity feature mentioned previously. However, the increased number of data does not necessarily mean higher level of accuracy.

### 4.5. Online and downloadable models

The growing number of ASPs (Application Service Providers) indicates the need for online processing and analysis. Additionally, fast downloading options let students, researchers and decision-makers easily access much more complex world models than those used 10 years ago.

### 4.6. Projects managed in global networks

Both the methodological needs and the organisational support of research projects encourage researchers to cooperate internationally. Large networks will facilitate the creation of integrated databases and will contribute to a better exploitation of the results. Networking will further help the cooperation of modellers and decision-makers.

### 4.7. High level of interactivity

Users and developers may count on intensive interactivity in software and model development, data and model exchanges. Modellers will provide feedback to software developers in a network, decision-makers and educators will be able to build models tailored to their own problems and needs.

### 4.8. "Floating" modelling philosophy[3]

Presumably, "floating" modelling philosophy is one of the most significant changes in the history of world modelling. Before the emergence of this approach, the structure, the functions and the equations of world models have predominantly been "frozen" in the programmes. All runs, based on the same data, gave the same results and the users could only study the built-in processes.

Floating models differ from traditional ones in two aspects. First, the structures are "burned" to the model only partially, the rest depends on the researcher's independent, floating view or interest. Secondly, analytical and simulation tools can be flexibly selected, depending on the problem, available data, previous results, etc. These options provide further opportunities for analysis and potential access to the conclusions for a wider audience. Interactivity will facilitate discussions, permanent development and data supply. Floating philosophy may be regarded as a new synthesis of the above listed trends. This approach correlates with the multi-dimensional extension of Sallach's "situated social ecology" (2002) and Devlin and Rosenberg's "layered formalism and zooming" (1996).

To deal with this practical problem, Sallach (2002) introduces "Situated Social Ecology" (SSE), a hermeneutics which intends to convey a multi-level interactive dialogue, capable of realising controlled models of social complexity. He refers to Devlin and Rosenberg who have formalised their analyses and have developed a technique called "Layered Formalism and Zooming" (LFZ analysis). LFZ analysis starts by an initial non-mathematical analysis of the data which makes use of mathematical formalisms. This formalism called "situation theory" is a branch of mathematics developed in the early 1980s, and discussed later by Devlin (1991). Following this first stage, the initial analysis is subject to a process of stepwise refinement and increased formalism. Whenever a problem is encountered, mathematical precision should be increased, applied specifically to the problem area. This process is referred to as "zoom in", and results in the in-depth, detailed examination of the problem. When the problem has been resolved, the researcher can "zoom out" again. At each step of the refinement process, the minimal possible level of formalism and the minimal possible level of precision should be used, thereby minimising the likelihood of any inadvertent alteration to the data under consideration. The analysis is checked against the data after each stage in the analysis refinement cycle. As a result, the balance between the mathematical and the sociological aspects of the analysis is determined not by the analysts but by the data. In short, the process of formalisation is used as an analytic technique. The

[3] The "floating" label in this context is derived from Karl Mannheim's "free-floating intelligentsia" concept (Mannheim 1991).

aim is not to produce a formal theory. Indeed, there may be so many symbols floating around that denote decidedly “soft” entities (such as contexts) that it would take a lifetime to come close to anything that might resemble a “formal system” in the mathematician’s usual sense (Devlin – Rosenberg 1996).

## 5. SUMMARY

No doubt that the rise of world modelling was determined by the development of computer technology, the milestones of all the three generations of world modelling being closely connected to the appearance of cupboard-sized, slow computers at first, then to the spread of desktop PCs, and finally to the proliferation of the Internet. This trend will lead us to network models, built-up by flexible modules and massive knowledge bases. Its methodology is capable of helping humanity to self-consciously envision itself and its environment in a time frame long enough and a scale large enough to provide an effective guide for future decisions and actions. In spite of this, global modelling is at present dominated by the praxis paradigm, not the science paradigm (Chadwick 2000). This is a dangerous situation from the science paradigm perspective because it implies that a model’s validity is judged acceptable if and only if policy-focused communities accept it and its implications.

Besides, this new discipline lacks proper academic institutional background. Many of the most common problems of modellers and policy formulating communities with global modelling stem from the lack of a formal study of the field in an academic environment. Insensitivity to paradigmatic framework, inappropriate application, and above all, unnecessarily cantankerous dialogue between policy formulators and policymakers on the one hand, and global modellers on the other, could be obviated by better education (Chadwick 2000). The above view refers to the last decades of the 20$^{th}$ century only. Technological development, changing attitudes of policymakers, activities of research institutes and societal reactions to global problems have been increasing the interest towards upgrading world models. Strengthening the theoretical basis of the science of world modelling is a necessary precondition of reaching this desirable goal.

## APPENDIX

Alphabetical list of best known world model acronyms:

AIM, Bariloche Model, CGE, CTRM, EPA, ERM, European VISIONS, Fair MC3, FRB Global, FUGI/GEWS, G–Cubed/MSG2, GEM (Global Economy

Model), GEM–E3, GEO–3, Global – Error Correcting Model, GLOBAL 2100, Global Scenario Group, Globesight, GLOBIO, GLOBUS, GREEN, IEA/ORAU, IEA–WEM, IMAGE 2.2, Interlink, International Futures, IPCC, IWM/Regional World 4, Klein model, LAWM, LINK, MEMMOD, MULTIMOD, NIGEM, Oxford Model, PoleStar, Quest, Regional WORLD-3, ROW, RW–3 and RW–4, SARUM/G–MAPP, SIM/GDP, Small Global Forecasting, STELLA, STRATAGEM, TERRA, Threshold 21, WaterGAP 2.1., WIM, WIOM, WORLD1, WORLD2, WORLD3/91, WW.

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