MODELING THE DYNAMICS OF GLOBAL SUSTAINABILITY, BASED ON DEVELOPED-DEVELOPING NATIONS DISTINCTION

by

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ABSTRACT

MODELING THE DYNAMICS OF GLOBAL SUSTAINABILITY, BASED ON DEVELOPED-DEVELOPING NATIONS DISTINCTION

Most models about global sustainability treat the world as if it were a homogeneous, single-nation system. However, the clustering observed among nations with respect to their economic development levels results in two distinct blocks with significantly different internal economic and demographic dynamics; developed (North) and developing (South) blocks. Interaction of these blocks and their local actions affect the global sustainability, as they are two interrelated actors in a closed system, namely the world. In this study, population, economic growth, welfare gap, energy supply and related pollution are identified as the key issues related to both global sustainability and the development discrepancy between North and South blocks. These issues are analyzed in a 'systems' perspective, focusing on their systemic, inseparable nature. A dynamic feedback model is constructed in order to simulate the long-term dynamics for key variables related to the above issues. The model is tested through well-defined validation procedures. First, its structure is tested, and then the model behavior is calibrated and tested with respect to the available data. Through these tests, the model is shown to be a useful platform to study alternative scenarios and policies through simulation experiments. Results from the simulation experiments reveal that stabilizing the population growth in South is vital for closing the welfare gap between blocks. Although South can reach North in terms of gross output, the gap between the output per capita levels prevails. A "non-renewable-resource-dependent" economic growth –currently prevailing system- does not seem viable globally, as cumulative energy load of South and North seems to overshoot global capacity. Hence, transition to alternative energy resources is vital for attaining global sustainability. Future energy crisis will have more serious and irreversible effects on South, as compared to North. Recovery of South from a non-renewable energy crisis can take place in a reasonable time period only with the investment support of North needed for building alternative renewable energy capacity.

ÖZET

KÜRESEL SÜRDÜRÜLEBİLİRLİK DİNAMİĞİ MODELLEMESİ VE GELİŞMİŞ-GELİŞMEKTE OLAN ÜLKELER FARKLILAŞMASI

Küresel sürdürebilirlik ile ilgili modellerin çoğu dünyayı homojen ve tek ülkeli bir sistem gibi incelemişlerdir. Ancak ülkelerin gelişmişlik düzeylerinde gözlemlenen gruplaşma, ortaya demografik ve ekonomik yapıları birbirinden çok farklı iki ülke bloğu çıkartmıştır; gelişmiş (Kuzey) ve gelişmekte olan (Güney). Bu iki ülke bloğu kapalı bir sistem olan dünyada iki baş aktör olduklarından, blokların birbirleri ile ilişkileri ve yerel davranışları küresel sürdürebilirliği doğrudan etkilemektedir. Bu çalışmada nüfus, ekonomik büyüme, bloklar arası refah uçurumu, enerji tedariği ve çevre kirliliği, küresel sürdürülebilirlik açısından kilit konular olarak belirlenmiştir. Sistemik bir yaklaşımla ele alınan bu konularla ilgili temel değişkenlerin uzun dönemli dinamiklerini incelemek üzere bir dinamik benzetim modeli kurulmuştur. Modelin geçerliliğinin sınanması aşamasında ilk olarak modelin yapısı test edilmiş, daha sonra ise modelin davranışları gerçek veriler kullanılarak kalibre ve test edilmiştir. Model, çeşitli senaryo ve politikaların benzetim deneyleri yardımıyla incelenmesi için kullanışlı bir platform oluşturmaktadır. Deneyler sonucunda görülmüştür ki Güney'deki nüfus artışının denetim altına alınması bloklar arası refah uçurumunun kapanması için yaşamsal öneme sahiptir. Güney, toplam ekonomik çıktı seviyesinde Kuzey'i yakalasa da, kişi başına düşen ekonomik çıktı düzeyleri arasındaki uçurum varlığını sürdürecektir. Kuzey ve Güney'in toplam enerji talebinin küresel kapasiteyi aştığı ve yenilenemeyen doğal kaynaklara bağımlı -yani bugün hakim olan- bir ekonomik büyümenin küresel boyutta olanaksızlığı saptanmıştır. Bu nedenle alternatif, yenilenebilir enerji kaynaklarına geçiş küresel sürdürülebilirlik açısından hayati önem taşımaktadır. Güney için olası bir enerji krizinin etkileri Kuzey'e göre daha ciddi ve geridönüşsüz olacaktır. Yenilenemeyen kaynakların tükenmesine bağlı bir enerji krizinden Güney'in makul bir sürede kurtulabilmesi, ancak Kuzey'in alternatif yenilenebilir enerji kapasitesi oluşturma alanında vereceği yatırım desteği ile mümkün görünmektedir.

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CFC	Chlorofluorocarbons
EIA	Energy Information Administration
GDP	Gross domestic product
GHG	Greenhouse gases
GSI	Global Sustainability Institute
GtC	Giga tones of carbon
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
IPPC	International Panel on Climate Change
ktoe	Kilotons of oil equivalent
LPG	Liquid petroleum gas
toe	Tons of oil equivalent
MIT	Massachusetts Institute of Technology
Mtoe	Million tons of oil equivalents
N	North
NGL	Natural gas liquids
PgC	Petagram of Carbon (1 billion tones of Carbon)
ppm	Parts per million by volume
R&D	Research and development
RoW	Rest-of-the-World
S	South
UN	United Nations
UNDP	United Nations Development Programme
UNPD	United Nations Population Division
WEC	World Energy Council
WRI	World Resources Institute
WWI	World Watch Institute
WWF	World Wildlife Foundation

1. INTRODUCTION

It was the late 19th century when the striking discussion about the sustainability of humankind first aroused. Thomas Malthus, in his *Essay on the Principle of Population*, questioned the sustainability of human existence on earth, given the conditions like food consumption and population growth at his time. Malthus argues that human population can easily overshoot the global carrying capacity, if not controlled (Malthus, 1895).

[illegible]

During the centuries following Malthus's doom theory, sustainability of the human development on earth became subject to many discussions. Especially in the last quarter of the 20th century, sustainability of the current pace of development became a hot issue in academic, governmental and public discussions (Meadows *et al.*, 1972; Ward and Dubos, 1972; Miller, 1972; Goldsmith *et al.*, 1972; Brundtland, 1987). The magnitude of the global economic activity, oil crisis in the seventies, and increasing perceived effects of industrial pollution were probably the major factors yielding this increased interest in the issue.

In those studies regarding global sustainability, probably the single common conclusion is the multi-disciplinary nature of the problem. Hence, the problem of sustainability of human activity on earth requires studying the world as a system composed of economic, environmental, social, and even political sub-systems at a global scale. These sub-systems are represented in various detail levels in the previously conducted research studies in order to point out problems that may set limits, or at least hard to eliminate obstacles for the economic and social development of mankind. The most commonly studied problems include pollution, exhaustion of natural resources, food scarcity, energy scarcity, global warming, population growth, and income distribution (Forrester, 1971; Meadows *et al.*, 1974; Herrera, 1976; Meadows *et al.*, 1992; Mesarovic and Pestel, 1974; Hughes, 1999).

Among these issues, income distribution at a global scale or welfare gap between nations attracts serious attention in the global sustainability context (Myrdal, 1957; Brandt, 1980; World Bank, 2002b; World Bank, 2003b). When the economic welfare indicators are studied, a significant clustering among nations is observed. The top and bottom clusters in this welfare spectrum are commonly referred as North and South, respectively. The most striking fact about this structure is the continuously widening gap between North and South blocks, and differing demographic and economic characteristics of these two blocks. As a result of this difference, the dominant dynamics in their economic, social and environmental processes are expected to be different; hence the obstacles they will encounter regarding sustainability will also differ in type, impact and timing. The significant influence of North and South's interplay dominated by the structural differences between these two blocks makes it vital to introduce this global welfare heterogeneity to global sustainability studies.

In the scope of this study, a simulation model is designed, using system dynamics methodology, in order to study the effects of individual behaviors, and interactions between these two distinct country blocks on global sustainability. By introducing two structurally distinct blocks, and interactions among them, we aim to study probable outcomes of this socio-economic difference.

2. LITERATURE REVIEW

The literature that inspired this study can be categorized into two groups; the ones providing the conceptual background and the ones providing the technical background. The first group focuses on the concepts of global sustainability and sustainable development, while clearly stating the inter-disciplinary nature and global scale of the problem. These characteristics mentioned in those studies clearly point out a research to cover multiple systems as in this research. On the other hand, the second group includes publications related to practical research aiming to study sustainable development via global modeling approach, providing a valuable background for this research.

2.1. Global Sustainability

"Global sustainability", a term being very popular in the recent 30 years, mainly refers to a state or mode of human-environment interaction that permits a sustainable development over time at a global scale. The key component of global sustainability, which also constitutes the goal, is sustainable development, and it refers to *"a development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*, with the words of Harlem Brundtland (1987).

Such a conceptualization of global sustainable development identifies three major components for this development pattern: environmental, economic and social components. Although these three components are generally studied in an isolated way from each other, interactions between these three highly integrated systems play the major role in setting the obstacles or providing the solutions in the course of sustainable development and attaining global sustainability (Hardi and Zdan, 1998).

Throughout the history of humanity, numerous problems related to these three main systems are identified and challenged. However, as a consequence of improved capabilities and increased size of human population, the number of problems and their complexity increased significantly. The ones attracting the most serious attention in the last two centuries include poverty, uncontrolled urban spread, air pollution, population expansion, natural resource depletion, food scarcity and insufficient water resources. Countless number of studies and enormous amount of effort is spent on studying these problems isolated from each other, but it was probably a biologist who formally stated the interrelated nature of some of these global problems. In the *Silent Spring* (Carson, 1962), the main focus of Rachel Carson is on chemical treatments in agriculture and their effects. She brings together toxicology, ecology and epidemiology, in order to demonstrate the interplay between the social and environmental systems. She points out the missed part in the interplay of these two systems; serious health problems due to the accumulated chemicals used in order to control the nature, which is the feedback from environmental system as a consequence of human action. Most importantly, this study shatters the assumption that the environment has an infinite capacity to absorb pollutants (IISD, 2002).

The Population Bomb (Ehrlich, 1972) of Paul Ehrlich followed *Silent Spring*. Similar to the former one, a holistic approach is introduced in this study, whose primary concern is demographic dynamics. This study mentions the interconnection between the population, resource exploitation and the environment (IISD, 2002; GSI, 2001).

Seventies was the period, where the environmental problems were started to be considered at a global scale. Major discussions in this context, which were probably induced by the oil crisis and observed population growth, pointed out the increased impact of human on the environment. The effects of economic and social systems on environment were no more local or regional, but they were clearly global. *Only One Earth* of Ward and Dubos (1972), and *Blueprint for Survival* (Goldsmith *et al.*, 1972) are two very imported publications in this era, and both aims to point a portfolio of truly global problems. These publications were important steps toward generating a public awareness towards perception of the global scale of the problems and need for an action to be taken to guarantee global sustainability.

Although former studies pointed out the scale of the problems and the interrelated nature of the systems responsible for these problems, the main frame for the global sustainability is clearly set in *The Limits to Growth* report (Meadows *et al.*, 1972) of the Club of Rome, which is an informal group of 30 individuals from different disciplines gathered together to provide a better understanding for the global problems. In this report, the term *"world problematique"* is used in order to represent the serious problems regarding the interdependent components of the world, as economic, political, natural and social. The Club of Rome argued that the serious problems that humanity faces have three characteristics in common; they occur to some degree in all societies, they are related to more than one component of the world system, and most important of all they interact with each other. Based on this argument, they propose that this kind of problems should be studied with a global and holistic perspective. *The Limits to Growth* is a study truly of that kind, which covers building a global model and conducting experiments regarding various global problems on the model. Results obtained are not very optimistic, and due to these conclusions this study is commonly referred as a declaration of a dooms-theory (The Economist, 1997; Percival, 1989). According to the report, the limits to growth would be reached within the following one hundred years, unless growth trends in population, industrialization, pollution and food production were altered. Additionally, it is concluded that a sustainable future is also possible, but it requires immediate action. Despite all critics regarding the conclusions and the scientific approach used in the report, it was a milestone in the process of building public awareness regarding global sustainability (Cole *et al.*, 1973; Mukherjee, 1996). It provides a valuable means to understand the interactions between the sub-systems of the world, and it is a clear message to public regarding the size and range of the incoming problems.

Several serious studies regarding the global sustainability follows the Limits to Growth study. Results obtained in some of these studies support the conclusions in the *The Limits to Growth* report, while another school of studies reject them. Despite the variability in the conclusions arrived, the common idea in all these studies is that current mode of development is not the one leading to global sustainability (Herrera, 1976; Mesarovic and Pestel, 1974; Leontief, 1977).

One of the key publications in the timeline of global sustainability topic is clearly "*The Global 2000 Report to the President*" (Barney, 1980), which is submitted to U.S. president Jimmy Carter in 1980. The importance of this report lies in its function of formally taking the global sustainability issue to the governmental arena. The report provides a comprehensive projection of global environmental impacts and resource supply issues until the year 2000. One of the features that differentiate the report is recognition of biodiversity for the first time as a critical feature for the proper functioning of the environment (GSI, 2001).

Following this report, another comprehensive report is published by United Nations. After a long period of study the commission headed by Harlem Brundtland published *Our Common Future: Report of the World Commission on Environment and Development* (Brundtland, 1987). Coverage of the report was almost unique by its comprehensiveness; it covered numerous serious global issues like population pressures and human resources, food security, species and ecosystem protection, energy supply alternatives, industrial production and efficiency, urban challenges, peace and security issues, and institutional and legal challenges (WEC, 2001). According to the report, by over-exploiting resources societies may damage their capability to meet the needs of their future generations. The report indicated that, until recently, interventions of human society on environment were small in scale and their impact was limited. However, parallel to industrial and demographic trends observed in recent decades, these interventions have become more drastic in scale and impact.

During the period between the publication of Brundtland's report and today, global sustainability has emerged as one of the major issues for numerous governmental, intergovernmental and non-governmental organizations. Efforts of these organizations materialized in various publications, including the valuable *World Development Report* series of World Bank, *Living in One World* by WEC, *State of the World* and *Vital Signs* series by WWI, and *Living Planet* series by WWF. Despite differing problems they focus on and perspectives have, common ideas depicted in these publications are the global scale and inter-disciplinary nature of the problems, incapability of current development mode in providing the solutions, and need for fast responses at global scale in order to alter these problems.

2.2. Global Modeling Studies

The establishment of the Club of Rome played a very important role in the global modeling practice. This informal group of 30 individuals from different disciplines believed that the *"world problematique"* should be studied at a global and holistic perspective and in this manner supported several global modeling studies aiming to understand the world system better.

The first global model associated with the Club of Rome was *WORLD-2*, which was developed by Jay W. Forrester and his research group, using the system dynamics methodology. The main focus of the study is on the conditions that will limit the population growth, and these limits are defined to be associated with pollution, food supply, crowding and natural resources. In order to study these limits, the model covers the interplay between the global demographic, industrial and agricultural sub-systems. Considering the global scope, the structure of the model is very simple. The model treats the global system as a unity, ignoring the economic, social, and environmental heterogeneities. This high-level approach enables Forrester to represent each one of global pollution, capital and natural resources with a single variable. Such a level of simplicity is consistent with the main purpose of the study, which is certainly not generating point predictions, but to capture long-term dynamics of these key variables. As Forrester indicates in the technical documentation of the model (Forrester, 1971), the model shall be used to indicate the direction in which the behavior will alter if certain changes are made in the system structure and the policies. Despite its simplicity, both the model itself and the results obtained are very influential in terms of understanding the mechanisms underlying *"world problematique"*. The structure of the model explicitly introduces the feedback loops between the different components of the world system, fostering the understanding of the interrelatedness of the system components. On the other hand, simulation runs regarding commonly proposed solutions reveal that such solution proposals lacking the holistic view fail to provide long-term solutions. Such interventions result in activating other limits through the complex feedback structure of the world system.

The popularity of *WORLD-2* and the appropriateness of the system dynamics methodology to the main purpose of the Club of Rome resulted in the initiation of a follow-up project which was then conducted by a research group in MIT. This group, lead by Donella Meadows, focused on building a new model using system dynamics methodology and the approach used by Forrester in *WORLD-2*. Similar to Forrester's model, its follow-up ignores global heterogeneity in covering global population, natural resources, economic activity, pollution and food supply. The main feature that differentiates *WORLD-3* from *WORLD-2* is probably the support provided to *WORLD-3* by a larger and diversified research team. This team, which was composed of scientists, specialized on the sub-systems of the global system, provided an important support which yielded improved model structures. In 1972, the group published the report of this study, including a brief description of the approach, the model used and the results obtained. Basic message in this widely-publicized report is that the exponential growth in world's population and economic growth is not sustainable and would lead to instabilities in the future. Popularization of the model attracted countless critics regarding the model. Among those, most relevant ones are that the model ignores both technological capabilities of humankind and the correction mechanisms of the free market. These two are proposed to prevent many of the problems before reaching the levels mentioned in *WORLD-3* (Cole, 1978; Percival, 1989). Additionally, "homogenous world" view employed in the model is also seriously criticized.

Several other global modeling studies are conducted following *WORLD-2* and *WORLD-3* models. One of those studies is the Mesarovic/Pestel model, which is also inspired by the 'promlematique' of the Club of Rome. However, the methodology used and the aggregation level chosen are significantly different from the preceding two global models. Criticizing the aggregation level used in *WORLD-2* and *WORLD-3* models, the project team constructed a model discriminating 10 regions selected according to both geographic proximity and a degree of similarity in culture, outlook, politics, and economic development (Meadows *et al.*, 1981; Mesarovic and Pestel, 1974). Mainly the multi-level hierarchy approach developed by Mihajlo Mesarovic is used as the modeling approach, but the model also contains some input-output, system dynamics and econometrics components. One of the remarkable features of the model is commodity flows represented both in monetary and physical terms. Such an expression can be accepted as a synthesis of ecological/system dynamics and traditional economics perspectives (Meadows *et al.*, 1981).

The Bariloche model, developed by a team of Latin American scientists, is a model containing five sectors (housing, education, other services and consumer goods, capital goods) and four regions (Developed regions, Africa, Latin America, and Asia). Although the Bariloche model is cited with other global models supported by the Club of Rome, its normative nature differentiates it from others. It is an optimization based global model and it was built to find out optimal policies to arrive a predetermined desired future state, instead of studying the expected global trends in the future like other models do (Herrera, 1976). Most important facts to note about this project are the model's assumption that there will not be any material scarcity in the future and existence of a pre-defined ideal society as a final goal to reach (Meadows *et al.*, 1981).

The Department of Environment in United Kingdom supported the System Analysis Research Unit (SARU) for a global model, and this support resulted in the construction of the *SARU* model. The *SARU* model is influenced by all the methodologies employed by its predecessors and it is a multi-region, multi-sector model. The main theoretical assumptions underlying this model are mainly based on neoclassical economics (Meadows *et al.*, 1981).

The Futures of Global Interdependence (FUGI) model is the first model developed by a non-Western modeling team, and it is motivated by concerns about the development of the third world, like Bariloche model. The Japanese project team employs a dynamic input-output analysis in the model, and mainly they are concerned with the effects of future industrialization in the developed and developing worlds (Mukherjee, 1996; Meadows *et al.*, 1981; Onishi, 2002).

In 1977, the final report regarding the United Nations Global Model was published. This input-output analysis based model, which was developed by a team lead by Wassily Leontief, differs from other input-output analysis based models with the environmental sector it included and by distinguishing physical and monetary flows. Additionally, with the reported conclusions this study can be considered as the most optimistic of all other studies mentioned. In the publication it is reported that the main limits to world development are political, social and institutional in character, and not physical as depicted in *WORLD-2* and *WORLD-3* models (Leontieff, 1977; Mukherjee, 1996; Meadows *et al.*, 1981).

Another item in the list of major global modeling studies is the *GLOBUS* model. This 25-region (and a rest-of-the-world entity) model is mainly focused on the interaction between political and economic developments. While aiming to incorporate a political aspect to economic development process, modelers assume that the world problems are mainly socio-political in origin, not physical. Although it is not explicitly cited, the perspective and approach employed in the *GLOBUS* model are very similar to system dynamics approach. The model is composed of state variables and flows that manipulate these stocks. Interactions among variables are explained with causal links, causal loops and polarity of these causal links. Apart from inclusion of politics, the conclusions reached also distinguish this study from the ones mentioned above. They conclude that the world is not moving towards a collapse, and the gap between the developed and developing nations will decrease in the 21st century (Bremer, 1987).

The final item in the list is an on-going project, led by Willard Fey and Ann Lam. *Ecocosm Paradox* project mainly focuses on the dominant motivation of governments, business enterprises and individuals towards consumption growth (Fey and Lam, 2000). According to Fey and Lam, life support system of earth cannot support the growth in human consumption amplified by several feedback loops embedded in the human instincts and business. However, they also state that slowing growth in order to save the environment can yield instabilities in global economy, which will be followed by political distress and wars. They use the term *Ecocosm Paradox* to represent this dilemma and they ask if a sustainable development path between these to tragic options is possible in their modeling study, in which system dynamics methodology is employed (Fey and Lam, 2000).

Among those eight studies completed, the Leontief, the *GLOBUS* and the Bariloche models identify the current socio-political path as the main source of global problems that can be encountered in the future. According to these three, physical capabilities of the earth are sufficient to support economic development, given that serious modifications are done on the consumption based life style, political conflicts and decision mechanisms regarding global issues. The remaining five models point out the power of exponential growth experienced in man-originated stress on environment, and the physical limits of earth we are approaching as a result of the current mode of development experience.

Finally, it should be considered that these eight models constitute the major studies in the literature of global modeling, so they do not constitute an exhaustive list. As it should be expected, these models have inspired several other studies aimed to extend and/or improve certain aspects of these studies (Mukherjee, 1996; Hughes, 1999).

3. PROBLEM DESCRIPTION AND OBJECTIVE

When the economic, social and environmental sub-systems of the earth interacting with each other are considered as a whole, the past trends raised doubts related to the sustainability of these relations. Exponentially growing global population coupled with increasing per capita output need, results in an exponentially increasing load on environment exerted by humankind. It was this growth pattern of environmental load that inspired studies on the ability of earth to support this growing load, or in other words sustainability of the current mode of interaction between nature and humankind.

In many studies, including the *WORLD* models and other pioneering works mentioned in the previous chapter, the global human-environment system is considered as a homogeneous one. However, by the second half of the 20th century, a striking heterogeneity is recognized in this system. Two blocks of countries are strikingly distinguished with very significant differences in population structure, welfare level and intensity of economic activity. These two blocks are classified as developed and developing nations, or with a popular convention as North and South respectively. These two blocks' interactions and the development paths they follow have significant impacts not only on local, but also on the global sustainability of economy-society-environment system.

Although both North and South blocks demonstrate an exponential increase in economic output, which is commonly represented by gross domestic product (GDP), per capita share of these output is significantly different between blocks. Population base of South, which is also growing exponentially, is mainly responsible for this difference.

Despite all fertility control efforts, global population is projected to stabilize at around a two-fold of the current level, 12 billion within next century. A more striking projection is that almost all of this growth from 5.3 to 12 billion is expected to occur in

South block (Barney *et al.*, 1991). In the same period, global industrial and agricultural output should be doubled in order to keep welfare approximately at the current level. Although a doubling of the global output is a probable scenario, most of this increase is not expected to be in the South, where demanding population will be born. Hence, the problem is no longer the possibility of needed increase in output, but the global distribution of that increase.

Another striking projection comes from the *World Energy Outlook 2002 Report* (IEA, 2002b). Global CO_2 emissions projected to double in a period of 60 years from 1970 to 2030 and almost 80 per cent of this increase is projected to be in the developing countries, or South. Considering that greenhouse gases will affect global climate through diffusion of these gases independent of the emission source, pollution emissions of South cannot be considered as a local problem. As a problem threatening the global commons like oceans and atmosphere, greenhouse gas emission is a truly global problem.

Finally, energy demand of current global economic activity is almost totally supplied from non-renewable natural resources (mostly from fossil fuels such as oil, coal and natural gas). Although a minor shift to alternative sources is in progress in North, even such a slow shift is not visible in the horizon for South. As a result, the dynamics of individual blocks' demand for non-renewable resources will determine the future availability of these resources. On the other hand, the capabilities of individual blocks to adapt to renewable energy resources, which seem to differ significantly, are vital in determining the impact of a potential scarcity on their economic activity.

All together these facts support the significance of North-South discrimination in the context of global sustainability. First of all they clearly have differing characteristics. Secondly, the dynamics of any block affects the companion's through interactions between these blocks and through impacts on global commons in a complex feedback system. These observations clearly raise the need for studying global sustainability in a dual-block global system setting.

Primary objective of this project is to study the global sustainability problem with a holistic perspective. In doing so, the North and South distinction will be an issue at the core and system dynamics will be used as the methodology in order to study the dynamics of issues affecting global sustainability in this complex feedback system. The main goal is to generate the expected behaviors of population, and economic output for individual blocks, based on the assumptions and limitations of the model. Since the central focus of the project is on differences and interactions between blocks, the experimental analysis focuses on the North-South distinction.

4. METHODOLOGY

The system considered in this study is a large-scale socio-economic one. Since the social aspect of the system is very important in determining the current and future status of the whole system, a qualitative approach with its flexibility and ability to cover social-human aspects may seem appropriate. The advantage of such an approach is supported with the fact that future status of this system will be seriously affected by hard-to-formulate and dynamic issues like politics, technology, and social motivations. On the other hand, with a qualitative approach, complexity and scale of the system makes it almost impossible to track and generate specific conclusions regarding the future state of the system. A formal quantitative modeling approach provides the ability to easily and precisely track a complex system under changing conditions, which is a very valuable attribute for the purpose of this research. Despite this advantage, many quantitative methods, in order to preserve mathematical tractability, force modelers to omit important qualitative aspects of the system that are too hard to quantify, which constitutes the most important disadvantage of these quantitative methods in studying socio-economic systems.

In selecting the methodology to be employed in this research, the above advantages and disadvantages of alternative approaches mentioned above are weighed. Consequently, system dynamics approach (Forrester, 1961; Forrester, 1968; Sterman 2000; Barlas 2002) is evaluated to be the most appropriate methodology considering the system of concern and the purpose of this study. Being a formal-quantitative modeling approach, system dynamics has some of the disadvantages of quantitative modeling approaches, but it represents one of the most suitable formal modeling methods to represent qualitative issues. In the very foundation of the methodology, system dynamics is designed especially to overcome limitations of quantitative approaches in studying systems with important qualitative aspects, especially socio-economic, human ones. This aspect of the methodology is clearly stressed by Jay W. Forrester, founder of the methodology, throughout *Industrial Dynamics* (Forrester, 1961). As Forrester states;

> "Knowledge of all forms can be brought to bear on forming an opinion of whether or not a model is suitable to its particular purpose. This means that model building and validation do not stop at the boundary where numerical data fail. It means that both have full access to the vastly richer sources that lie in the non-quantitative areas… By hypothesizing quantitatively about these areas, the day may be hastened when firmer facts and measurements are available."
>
> (Forrester, 1961, pp.129)

This aspect of the methodology is very-well summarized by Sterman as;

> "…from the beginning (system dynamics approach) stressed the development of models unconstrained by the demands of analytic tractability, based on realistic assumptions about human behavior, and utilizing full range of data, not only numerical data, to specify and estimate relationships"
>
> (Sterman, 2000, pp.37)

This approach provides the tools and methods to incorporate important qualitative components of the system to the formal representation as well as quantitative components. The simulation-based experimentation procedure of system dynamics helps to understand the dynamic complexity of the studied system, to identify the important policy entrance points, and to test long-term system-wide effects of policies (Sterman, 2000). This is an important advantage of the methodology over other quantitative approaches, considering the non-linear feedback nature of system, which is hard or almost impossible to analyze through analytical methods due to its complexity.

The dynamic behavior of the system over time is the core point of system dynamics, and in studying these behaviors, the methodology does not aim to predict the values of the system variables point by point. The purpose is to "predict" the *dynamic patterns* that would result from adopting a given set of policies. This aspect makes system dynamics particularly applicable to long-term strategic policy analysis of possible changes in historic trends. Most of the other quantitative approaches are best suited to short-term precise prediction in situations that do not differ from those that have occurred in the near past (Meadows, 1985). This difference of the methodology is another aspect that makes it particularly appropriate to the problem of concern.

In this methodology, two main building blocks are used in modeling the system of concern. *Stocks* are briefly accumulating variables that identify the state of the system at a particular time. These stocks are manipulated via instantaneous inflows and outflows, which are referred as *flow* variables.

A simple system regarding atmospheric CO_2 accumulation is presented in the stock-flow representation form in Figure 4.1. In this representation, the *stock* variable of the system (*Atm_CO2*) is represented with a rectangular box. The thick arrows with valves pointing to, and emerging from this *stock* variable represent the *flow* variables related to this *stock*. Arrowheads indicate the direction of these flows. According to this representation, inflow to the stock is emissions by fossil fuel usage (*EmsByFossilFuel*), and outflow from the same stock is the diffusion flow (*CO2_Diffusion*). In each time period, magnitude of *EmsByFossilFuel* indicates the amount of CO_2 added to the atmosphere, whereas *CO2_Diffusion* represents the amount flowing out of the atmosphere via diffusion. Remaining variables in the figure are called *auxiliary* (or converter) variables and they are used for calculation of flows and defining the links between components of the system. Finally, curved thin arrows indicate causal relation between two variables in the system. In this simple example, the magnitude of *EmsByFossilFuel* is formulated as a product of fossil fuels used (*Fossil_Fuel_Used*) and the average emission rate per fossil fuel usage (*Emissions_Per_Fossil_Used*). Refer to Equation (4.2) for the details of this calculation. The magnitude of the diffusion outflow is dependent on the amount of CO_2 in the atmosphere (*Atm_CO2*) and a constant diffusion fraction (*CO2_Diffusion_Frac*). In each time step a certain fraction of the CO_2 in the atmosphere is assumed to flow out o via diffusion. Magnitude of this outflow is calculated to be the product of *Atm_CO2* and *CO2_Diffusion_Frac* (see Equation (4.3)). To sum up, in each time interval an amount equal to the *EmsByFossilFuels* is added to the atmosphere and in the same interval, an amount equal to the *CO2_Diffusion* disappears from atmosphere (see Equation (4.1)).

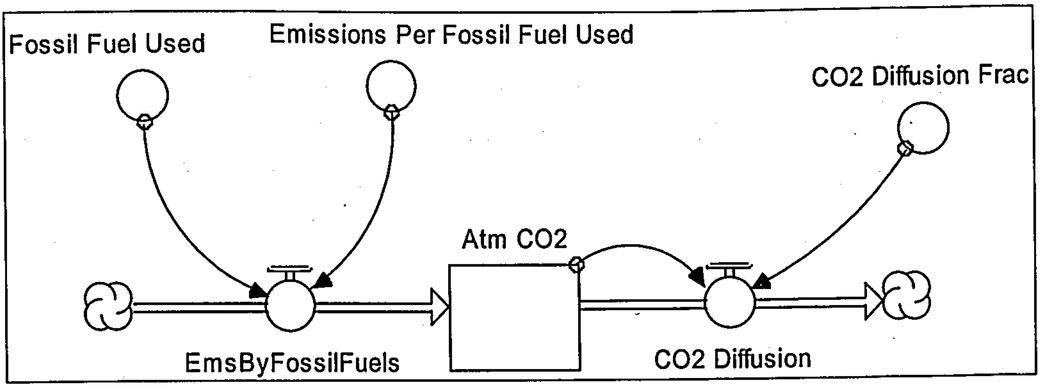

Figure 4.1. Representation of a simple stock-flow model

Models build with this methodology corresponds to a set of differential or difference equations, in which stocks represent state variables and flows represent rates of change. The stock-flow representation of the simple CO_2 example is given in Figure 4.1. Differential equations regarding the same system are also given in Equations (4.1), (4.2) and (4.3).

$$Atm\_CO2(t) = Atm\_CO2(t - dt) + (EmsByFossilFuels - CO2\_Diffusion) \times dt \quad (4.1)$$

$$EmsByFossilFuels = (Fossil\_Fuel\_Used) \times (Ems\_Per\_Fossil\_Fuel\_Used) \quad (4.2)$$

$$CO2\_Diffusion = Atm\_CO2 \times CO2\_Diffusion\_Frac \quad (4.3)$$

The methodology, which is composed of an iterative modeling process and a following experimentation, is mainly composed of five stages (Sterman, 2000). The first of these five stages is problem articulation, which includes the identification of the dynamic problem. Identifying the problem requires setting the boundaries such that the system at hand will reflect the main characteristics of the problem, determining the key variables and setting the time horizon of the study.

In the second stage of the methodology, modelers are expected to develop a dynamic hypothesis regarding the system being studied and its problematic behavior. This process requires characterization of the feedback relationships between system variables with respect to the observed past behavior of the system.

The third step consists of building the simulation model based on the hypothesis developed regarding the causal structure. Following the building of stock-flow structure of the model, parameters, equations and initial conditions are estimated based on the observed past data and system behavior.

The fourth step of the methodology is testing the validity of the built model with respect to the problem of concern. Testing process, which is performed almost concurrently with model building, includes the validation of the model structure (testing the built structure against developed hypothesis and the real system relations) and its behavior (comparing the output of the model with observed real dynamic behavior). The plausibility of the model under extreme conditions and robustness of model behavior to uncertainties in initial conditions and parameters are important criteria in validity testing (Barlas, 1996).

The final step of the methodology is using the constructed and validated model in experiments for the purpose of policy analysis and design. This experimentation step enables to study behavior of the system under various policies, scenarios and conditions. Results obtained throughout the experimentation procedure provide effective information that helps to identify policy entrance points, and evaluate and design useful policies.

5. OVERVIEW OF THE MODEL

The model developed in this study aims to cover interrelations between economic, demographic and environmental systems, in the context of global North-South differentiation. Considering the aggregation level used in the model, defining and quantifying relations especially between economic and environmental systems is a sophisticated task. In order to simplify the problem, energy resources are selected to represent outputs from environment to economic system, and greenhouse gas emissions represent the outputs from economic system to environment. Assumptions and facts underlying these selections are presented in the related sector discussions in detail.

As explained in the problem description stage, the objective is to study the global system as a whole with a North-South discrimination. This statement requires classifying economies to belong either to North cluster, or to South cluster. However, during the pre-modeling research stage, it is evaluated to be unrealistic to draw a single line to define a border between North and South clusters. It is evident that there are some economies hard to be classified in either North or South cluster. Classifying these countries in any of these two clusters will result in decreased in-group homogeneity, and will alter the characteristics of that country cluster. This major problem, which is discussed in Appendix A in detail, requires defining a third class of countries. This third cluster of countries is called the Rest-of-the-World (RoW) cluster, and includes those countries that cannot be classified as North or South. A very similar approach is also employed in some of the previous global modeling studies (for instance Bremer, 1987). Refer to Appendix A for the criteria used in classifying economies and the list of countries included in each cluster.

Although main focus of the study is on North and South clusters, significance of the RoW cluster's contribution in certain global issues like pollution, energy consumption and population make it inevitable to represent Rest-of-the-World (RoW) cluster in the model. Hence, the model contains this third country group as well as North and South country classes. Two extreme options for integrating the RoW block to the model are either to introduce required values belonging to RoW simply as exogenous inputs to the model or to model RoW block as detailed as North and South blocks. First option requires generating projections for the RoW block in the necessary variables, and introducing these variables as pure exogenous inputs. This option somewhat damages the objective of taking a systemic approach. On the other hand, the second option requires significantly enlarging the model in order to generate the variables of the RoW block endogenously, which demands increased structural complexity and parameter estimation effort. However, these additional efforts have a limited marginal return with respect to the main objective of the study. Hence, a hybrid approach in between these two extremes is employed. For the issues of concern, simplified structures in order to generate responses of the RoW block are constructed. Assuming that RoW block represents class of economies in between North and South, key variables used in these structures are estimated by using their counterparts in North and South blocks. For example, in North and South blocks there are structures built to generate fertility rates endogenously and this fertility value is used in generating birth rate. For RoW block, instead of building the detailed model structure related to fertility level, this variable is calculated as a weighted average of North and South levels, which are endogenously generated by the model. Then this estimated fertility level is used to generate birth rate in RoW with a simpler structure. This example illustrates the main logic of the approach; detailed discussions of the structures belonging to RoW are made under related sections.

The model is composed of nine sectors grouped under four sector groups. These sector groups correspond to economic activity, population, resource usage for energy and pollution caused by greenhouse gases. Each sector group contains at least two sectors, one for the North and one for the South block. Pollution related sector is the only exception as it is a single sector representing global pollution. As mentioned above, additional structures to represent the Rest-of-the-World (RoW) block are also introduced to some of these sector groups. A high-level representation of these sectors and their interactions are given in Figure 5.1.

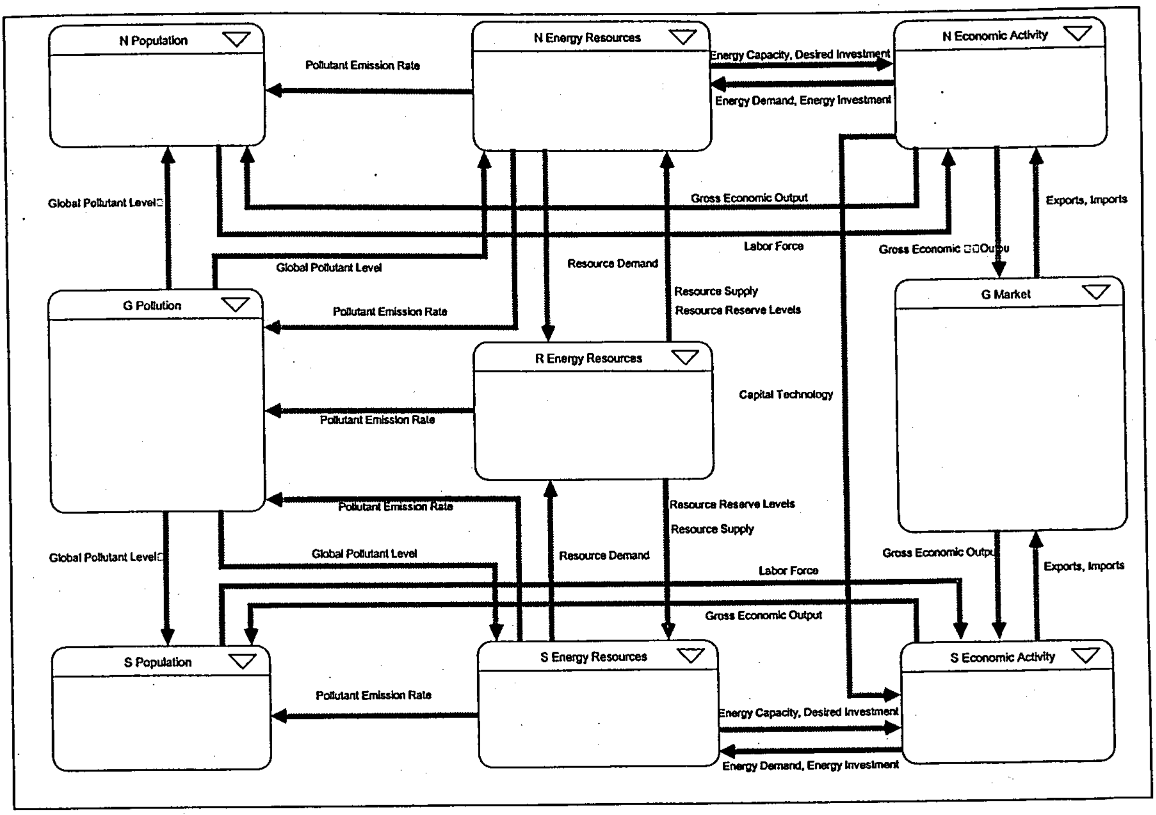

Figure 5.1. High-level representation of the sectors of the model and input-output relations between these sectors.

In the following sections, general overviews of the sector groups and the main interactions with other sectors are presented. Underlying assumptions, the approach used, and the structural details of sectors will be discussed throughout Chapter 6.

5.1. Population Sector Group

This group is composed of two sectors, which are the population sectors of North and South. The sectors used for North and South are almost identical, only some parameter values and graphical functions differentiate these two sectors. The structure constructed in these sectors is mainly responsible for simulating the population size, age structure, and average life expectancy of the members of the population. No migration relation is defined between population blocks of North and South, so these two sectors have no direct interaction.

Dynamics of key variables in these sectors are influenced by the feedbacks from economic activity and pollution sector groups. Income generated per capita in economy sectors determine the health expenditures and affect the life expectancy. On the other hand, as a wealth indicator it is also assumed to affect the number of children desired per woman. Other factors that affect the life expectancy are global pollution level and local pollution emissions related to the pollution sector.

Details of this sector group are discussed in Section 6.1.

5.2. Energy Resources Sector Group

Three sectors are included in this group. Two of them belong to North and South, and they are mainly responsible for simulating the energy supply for the economic system. These sectors include structures related to allocation of energy demand among renewable and non-renewable resources, maintaining the non-renewable resource stocks, capacity adjustment for renewable energy generation and technological improvement in renewable energy productivity. As in the population group, these two sectors belonging to North and South are very similar. The only structural difference between these two is related to the improvement of renewable energy productivity, as will be discussed later.

The third sector of the group represents the state of global non-renewable energy resources reserves and production from these reserves. The sector covers dynamics of new reserve discoveries and resource extraction/production from the discovered reserves. This sector acts as the only non-renewable energy resource supplier of the model. The sector directly interacts with the other energy sectors by receiving demand from them for non-renewable resources and supplying to meet these demands.

Details of this sector group are discussed in Section 6.2.

5.3. Economic Activity Sector Group

This group of sectors is composed of three sectors. The economic system represented in these sectors is supply-driven systems with two types of homogenous goods. Apart from the determination of gross economic output of North and South blocks, these sectors also simulate specialization of blocks among high technology and low technology goods production, dynamics of output-capital ratios experienced in the production of these two output types, and blocks' investment capabilities.

The sector related to Rest-of-the-World (RoW) block is constructed in order to generate an approximation of its economic output to be used in resource usage and pollution generation issues. Instead of explicitly modeling an economy for RoW, its economic output is estimated by using approximate correlation, based on the instantaneous parameter values of North and South. For example, an estimated productivity, which is calculated as a weighted average of productivity figures of North and South, is used in output calculations of RoW block.

The output generated in these sectors determine the welfare level, which is represented by output per capita, experienced in each block. This level provides feedback to both life expectancy via improved health services and to population growth via decreasing desired number of children. On the other hand, output generated in this sector is mainly responsible for the environmental stress of man on environment. This stress is in the form of resource usage to support economic activity, and emissions of the economic activity byproducts, or pollutants, to the environment.

Details of this sector group are discussed in Section 6.3.

5.4. Pollution Sector

This single sector represents the dynamics of pollution generation as an impact of economic activity, and global diffusion of this pollution. As explained in Section 6.4, greenhouse gases (GHG) are selected as the pilot pollutant, and a structure that is representative of its generation and diffusion is constructed. In the sector, the level of pollutant in the atmosphere and its level in the global sinks are separated. The atmospheric level increases by emissions due to non-renewable resource usage to support economic activity. On the other hand, an outflow from atmospheric pollutant stock to global pollutant sinks is defined. This flow represents the concentration driven diffusion of pollutants to global sinks, by which mainly oceans are meant.

The sector mainly interacts with energy sectors in determination of the GHG emissions, as they are mainly dependent on the amount of non-renewable resources used. On the other hand, global pollution level both affects the life expectancy in population sectors, and provides feedback to the energy sector related to allocation of energy demand among non-renewable and renewable resources.

Details of this sector group are discussed in Section 6.4.

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6. DESCRIPTION OF THE MODEL

In this chapter, each sector group is described in detail. For each sector group, background information and current trends, fundamental assumptions and the model structure constructed are given. While documenting the model structures, only one of the two sectors corresponding to North and South are presented, as long as they are structurally identical.

In order to discriminate the variables belonging to each sector, a one-letter prefix is used while naming the variables used in the model. According to this convention *N* stands for North, *S* stands for South, *R* stands for Rest-of-the-World and *G* stands for global. For example *N_LifeExpectancy* and *S_LifeExpectancy* represent the average life expectancy values of North and South blocks, respectively. In providing the variable definitions in this chapter, these prefixes are omitted for identical variables used for multiple blocks. For example, definition for *LifeExpectancy* will be provided in place of the two variables mentioned above.

6.1. Population Sector Group

6.1.1. Background Information

The size of the global population and its rate of change have significant importance in determining the environmental stress caused by mankind and also determining the scale of the future economic activity. Current trends and future expectations regarding the population dynamics are significantly different between the two country blocks subject to this study, namely North and South.

Currently 70 per cent of the global population is living in the countries classified as South, opposed to the 15 per cent living in North (World Bank, 2003). Additional to the current situation, share of global population living in South is projected to increase during the following five decades (UNPD, 2003; Barney, 1991). In the projections of United Nations, countries classified as South demonstrate a population growth with a decreasing rate of change, whereas North with a stabilized population in the current decade is expected to change little during the following 50 years. Furthermore, a significant fraction of countries in North is anticipated to experience negative population growth rates after 2030 (UNPD, 2003). Based on these projections summarized in Table 6.1, it can be concluded that a significant fraction of the global population growth in the 21st century will be South based. Hence, the dynamics of population growth experienced in South will be very influential in determining the global population levels in the future.

Table 6.1. Estimated and projected population of the world, and major development groups according to fertility variant

Major Area	**Population (millions)**			**Projected Population in 2050 (millions)**		
	1950	***2000***	***2003***	***Low***	***Middle***	***High***
World	2519	6071	6301	7409	8919	10633
More Developed regions	813	1194	1203	1084	1220	1370
Less Developed regions	1706	4877	5098	6325	7699	9263

Apart from South's large population base, the age composition of that population is another important factor underlying the expected population growth in South. The median age of the population is around 23 years at South, compared to a median age of 38 at North (UNPD, 2003). Striking difference between the compositions of these two populations is clearly evident in Figure 6.1 and Figure 6.2, which are reproduced from the *Global 2K Revisited Report* (Barney, 1991). This young composition of population provides a momentum to the population and it will be responsible for a significant population growth, even though fertility decreases to replacement levels. On the other hand, current composition of North is almost evenly distributed according to age groups, but this fact coupled with expected low fertility levels will most probably result in an older North population with a negative rate of change after some point in the following century (Cohen, 1995).

Finally, fertility rates of women also demonstrate significant differences between North and South. Although it seems to be a little above the replacement level for North, it is projected to decrease below two in the close future (UNPD, 2003). On the other hand, fertility per women experienced in South is approximately four, and in the projections of the UNPD it seems to stay above the replacement even at the middle of 21st the century (UNPD, 2003). Such a fertility rate with the population characteristics mentioned above makes South a fast growing population, in need for more economic output and energy resources, at least in order to stay at their current life standard.

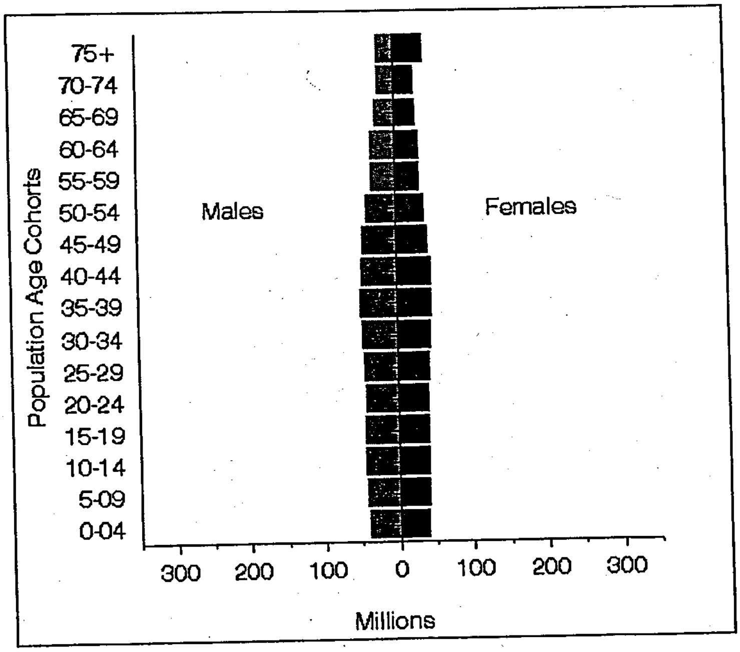


Figure 6.1. Estimated age distribution of North in the year 2000

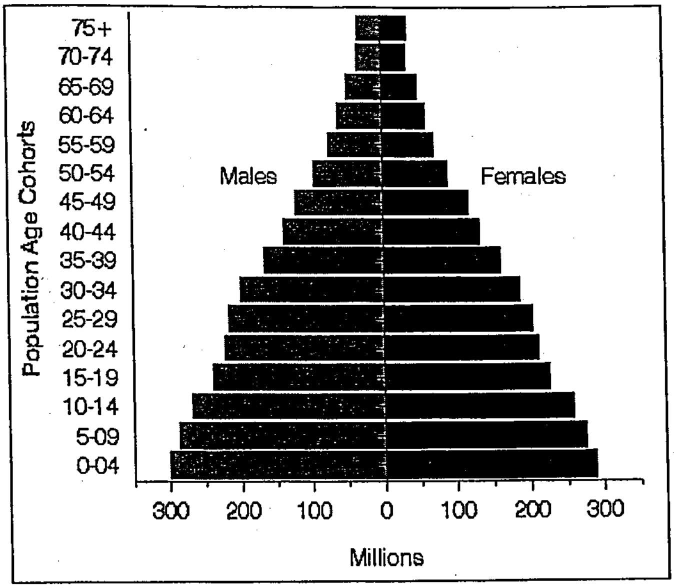


Figure 6.2. Estimated age distribution of South in the year 2000

6.1.2. Fundamental Approach and Assumptions

The population structure used in *WORLD-3* model of Meadows *et al.* (1974) is evaluated to be appropriate for the scope of this study. Hence, the population structure employed in this model is significantly inspired by the one used in *WORLD-3* model. However, certain sub-structures are added, some are discarded and some are modified according to the requirements of this study. Additionally, some parameters are updated based on the recent demographic trends. In the following overview of the population structure, main focus will be on the modifications performed for this study. A detailed documentation of the original structure used in *WORLD-3* can be found in *Dynamics of Growth in a Finite World* (Meadows *et al.*, 1974).

As most of the sector groups of this model, the population sector is composed of two identical sectors, each one responsible for a single block's population behavior. These identical population structures differ only with some graphical functions and initial values of certain parameters.

No direct relation is defined between the population structures of North and South. The underlying assumption is the insignificance of existing migration flows between blocks to effect the overall population dynamics, and existing regulations of North preventing these flows from reaching significant figures in the future. In this manner, population structures belonging to each block are considered as two standalone structures and no migration relation is defined in the base model. Finally, populations of both North and South are assumed to be composed of equal number of males and females.

6.1.3. Description of the Structure

The demographic dynamics of North and South differentiate mainly due to three inter-related factors. The first of them is the composition of population with respect to age groups. The size of a population is not a sufficient statistic to rely upon in studying the long-term dynamics of a population. It is the composition of the population with respect to age groups, which represents the momentum of the growth of a population, as mentioned above. Hence, in order to represent the different population dynamics of North and South due to age composition differences, a multi-stock population structure is preferred. Similar to the structure used in *WORLD-3,* population is represented by multiple age groups. Instead of using four age groups, as in *WORLD-3,* three age groups are used in this model.

The remaining two factors that play a major role in population dynamics are life expectancy at birth and fertility per woman. The structures representing the dynamics of these two factors are mainly inspired by the counterparts in the *WORLD-3* model. The minor modifications performed on these structures are depicted under the specific headings.

As representative of the identical population sectors, stock-flow diagram of the population sector of North is given in Figure 6.3. Sections of this sector will be discussed in the following paragraphs.

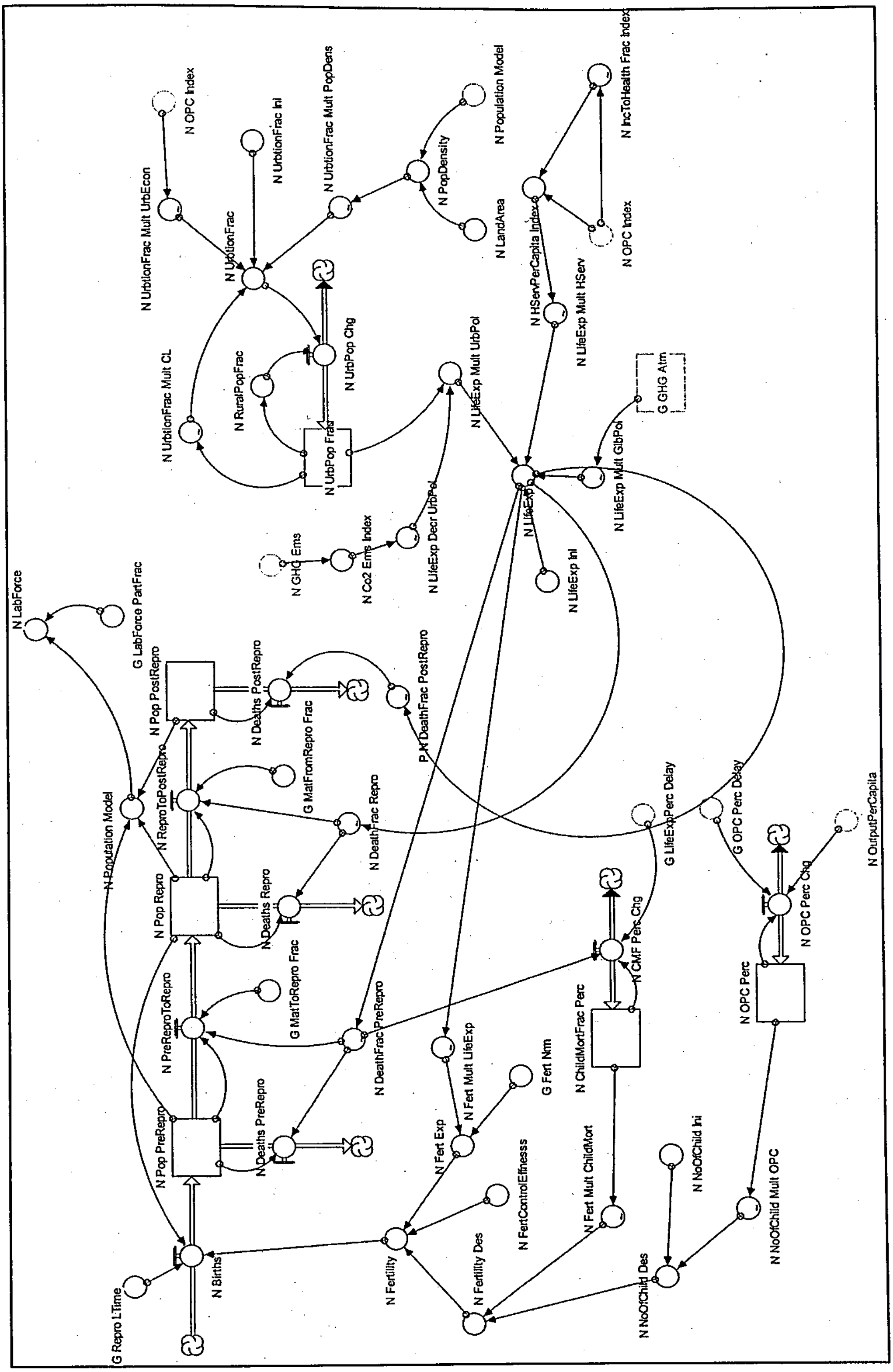


Figure 6.3. Stock-flow diagram of the population sector for North

Population related variables used in this sector group are listed in Appendix B with their brief descriptions and units.

As mentioned in the previous section, the main dynamics of the population is hypothesized to be dominated by the fertility level, life expectancy and population base. Major feedback relations between these factors are represented by a causal-loop diagram in Figure 6.4. Four main feedback loops are identified in this causal-loop diagram. First of the loops is between the births and population. As population grows, the birth rate increases and this increase results in further population growth. This is a reinforcing feedback loop (marked with a "+" sign), through which system reinforces any change (growth or decline) in the population. A second reinforcing feedback loop passes through income per capita and desired fertility level, and this loop may be named as *"poverty trap"*. As population grows, income per capita decreases (assuming other factors like income stay constant), and this in turn causes desired fertility levels to increase after a delay. Direct consequence of increased desired fertility is increased birth rate and further growth in population.

Remaining two feedback loops are characterized as balancing loops (marked with a "-" sign), through which system reacts against any change in population and attempts to balance that change. The feedback loop containing the population and the death rate is one of them; the death rate increases as population grows and increased death rate balances the growth in population. The loop including the population, health services per capita and life expectancy is also a balancing feedback loop. According to the causal relations in this loop, a growth in population results in decreased health services per capita. After a certain delay, decreased health services affect average life expectancy, and it also decreases. Following the decrease in life expectancy, death rate increases. As in the former loop, a change in population induces a reaction in the opposite direction via changing death rates, according to this causal loop.

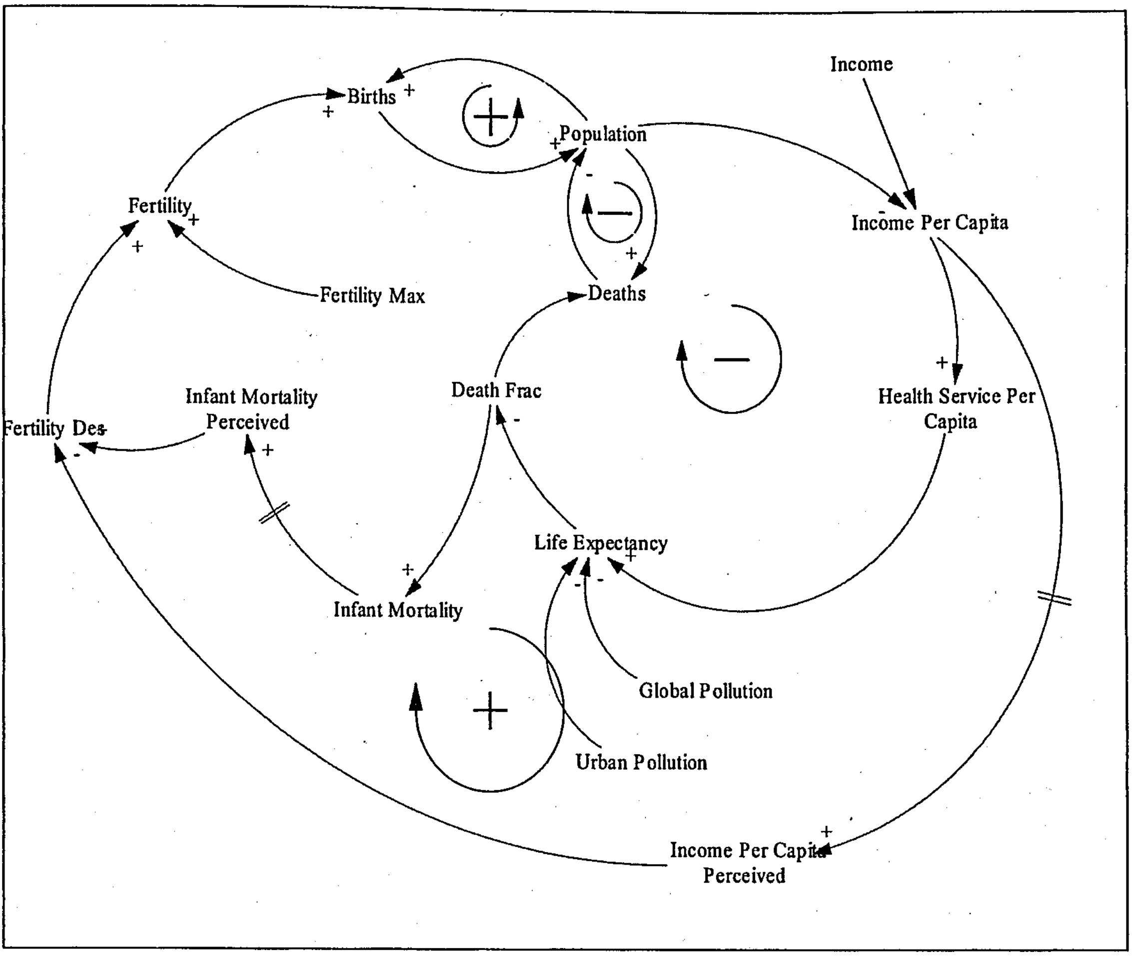


Figure 6.4. Simplified causal-loop diagram for the population sector

<u>6.1.3.1 The Structure Related to Age Composition of the Population.</u> The aging-chain structure employed in this model is very similar to the one used in *WORLD-3* model, but the age groups are defined differently. As the main dynamics of the population is driven by the size of the reproductive portion of the population, age groups are defined according to the reproductive capabilities, which necessitates introduction of pre-reproductive, reproductive and post-reproductive sub-populations. First group represents people under the age of 15, second group represents the population between the ages of 16-45 and the final group is the population with an age of above 46 years. As it can be seen in Figure 6.5, these three age groups of the population are represented by stock variables (*Pop_PreRepro, Pop_Repro, and Pop_PostRepro*). Levels of these stocks are manipulated through deaths (*Deaths_PreRepro, Deaths_Repro, and Deaths_PostRepro*), births (*irths*), and flows between age groups (*PreReproToRepro, ReproToPostRepro*).

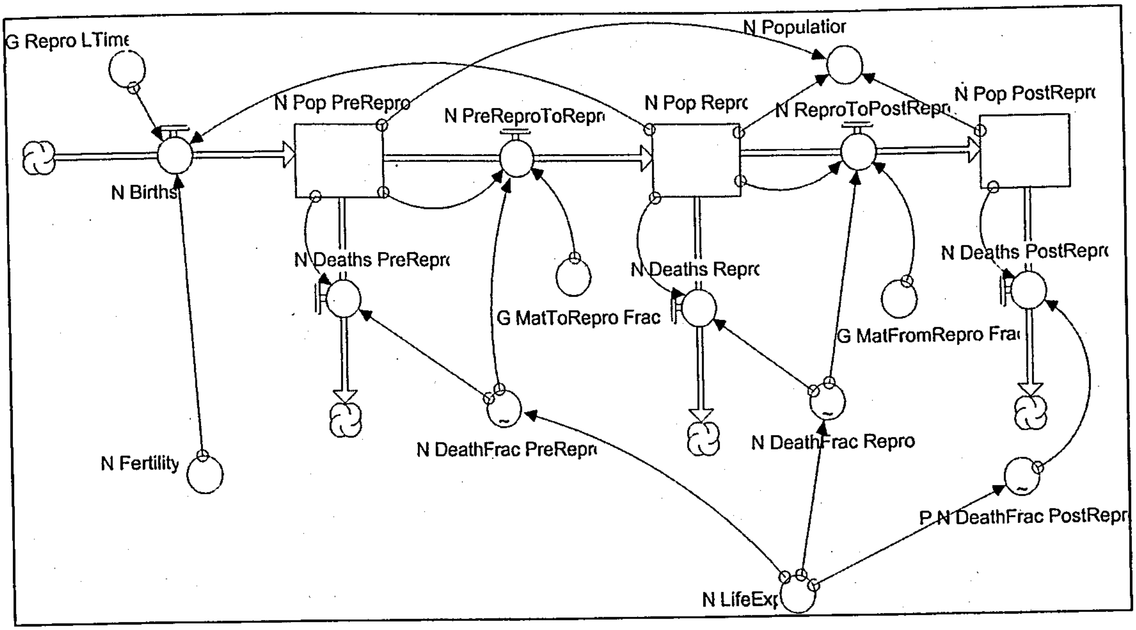


Figure 6.5. Model structure related to the age composition of population

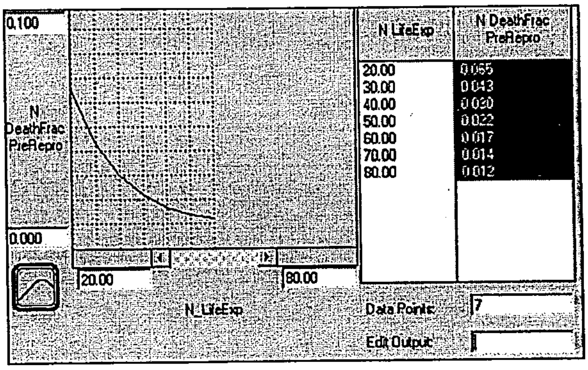
As seen in Figure 6.5, only inflow to the pre-reproductive group (*Pop_PreRepro*) is the births flow (*Births*). The magnitude of this flow is calculated to be a product of total number of fertile women in the population and the average number of births given by a woman in a time period (year). In accordance with the age group classification, the fertile period of a woman (*Repro_LTime*) is defined to be 30 years (period between ages of 16 and 45), and a woman is assumed to be equally likely to have a child in any year during this period. Based on these assumptions, the number of births given per woman per year is calculated to be total fertility per woman (*Fertility*) divided by the length of the reproductive period (*Repro_LTime*), which is 30 years. In calculating the total number of births (*Births*), it is assumed that male and female populations are equal in both North and South populations. Refer to Equation (6.1) for this calculation.

$$Births = (0.5 \times Pop\_Repro) \times (Fertility/Repro\_LTime) \tag{6.1}$$

Each sub-population has at least one outflow, which represents the deaths from that age group. These death outflows (*Deaths_PreRepro, Deaths_Repro,* and *Deaths_PostRepro*) are dependent on the death fraction (*DeathFrac_PreRepro, DeathFrac_Repro,* and *DeathFrac_PostRepro*) and the size of the population group. Death fractions are defined to be a non-linear function of average life expectancy, and these functions are derived using their counterparts in *WORLD-3* model. Equation used for determination of death flow from pre-reproductive population, which is identical to the ones used for other sub-populations, is given in Equation (6.2).

$$Deaths\_PreRepro = Pop\_PreRepro \times DeathFrac\_PreRepro(Life\_Exp) \qquad (6.2)$$

Function used for *DeathFrac_PreRepro(Life_Exp)* in Equation (6.2) is given in Figure 6.6. This figure demonstrates the tool of the Stella 7.0 software (dynamic simulation software that is used in this study) for defining graphical functions. The x-axis of the graph represents life expectancy (*Life_Exp*), and y-axis represents the corresponding death fraction values (*DeathFrac_PreRepro*). In this interface major points of the graph are also presented in a tabular form next to the graph. The graphical functions used to represent *DeathFrac_Repro(Life_Exp)* and *DeathFrac_PostRepro(Life_Exp)* are also given in Figure 6.7 and Figure 6.8, respectively.

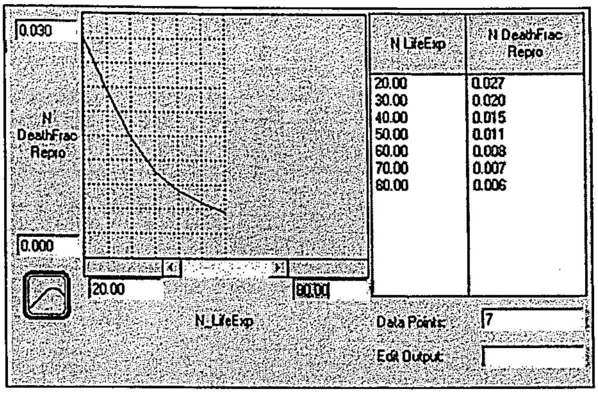


N LifeExp	N DeathFrac PreRepro
20.00	0.065
30.00	0.043
40.00	0.030
50.00	0.022
60.00	0.017
70.00	0.014
80.00	0.012

Data Points: 7

Edit Output:

Figure 6.6. Death fraction of pre-reproductive population as a graphical function of life expectancy (North)



N LifeExp	N DeathFrac Repro
20.00	0.027
30.00	0.020
40.00	0.015
50.00	0.011
60.00	0.008
70.00	0.007
80.00	0.006

Data Points: 7
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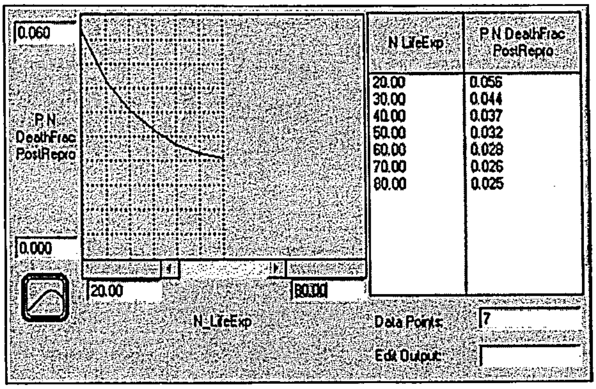
Figure 6.7. Death fraction of reproductive population as a function of life expectancy (North)



N LifeExp	P N DeathFrac PostRepro
20.00	0.056
30.00	0.044
40.00	0.037
50.00	0.032
60.00	0.028
70.00	0.026
80.00	0.025

Data Points: 7
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Figure 6.8. Death fraction of post-reproductive population as a function of life expectancy (North)

Apart from the death outflows explained above, pre-reproductive and reproductive groups have another outflow. This second type of outflow represents the transition flow from a younger age group to an older one as time proceeds, and they can be referred to as aging flows (*PreReproToRepro* and *ReproToPostRepro*). These flows are defined to be dependent on the level of population group from which members flow (*Pop_PreRepro* and *Pop_Repro*) and the corresponding fraction (*MatToRepro_Frac* and *MatFromRepro_Frac*).

Initial values for the three sub-populations of North and South are given in Table 6.2. These initial values are calculated by aggregating all the individual country statistics for the year 1975, based on the *World Development Indicators* data series (World Bank, 2003).

Table 6.2. Initial values of population stocks of North and South representing their level in 1975 (million people)

	North	South
Pre-Reproductive Population	215	1.000
Reproductive Population	280	900
Post-Reproductive Population	170	500

<u>6.1.3.2. The Structure Related to Average Life Expectancy at Birth.</u> The average life expectancy is assumed to be affected by the changes in health service conditions and changes in exposure to pollution. As food production/consumption is not included in this study, the role of nutrition in life expectancy is ignored.

The simplified stock-flow structure used for generating the dynamics of life expectancy is given in Figure 6.9.

As presented in Figure 6.9, average life expectancy is defined to be affected by global pollution (*LifeExp_Mult_GlbPol*), urban pollution (*LifeExp_Mult_UrbPol*), and health services available (*LifeExp_Mult_HServ*). These affects are formulated as multipliers to be used with a base life expectancy (*LifeExp_Ini*) value in order to get the actual life expectancy.

As it is mentioned in the above paragraph, exposure to pollution is defined to be in two forms. The first form is the exposure to global pollution originated from sources all over the world and diffused on global scale. For example effects of pollution generated by global economic activity on Sub-Saharan tribes with minimal contribution to this pollution can be categorized as this form of exposure to pollution. In evaluating this type of exposure, global pollution level is used (*G_GHG_Atm*).

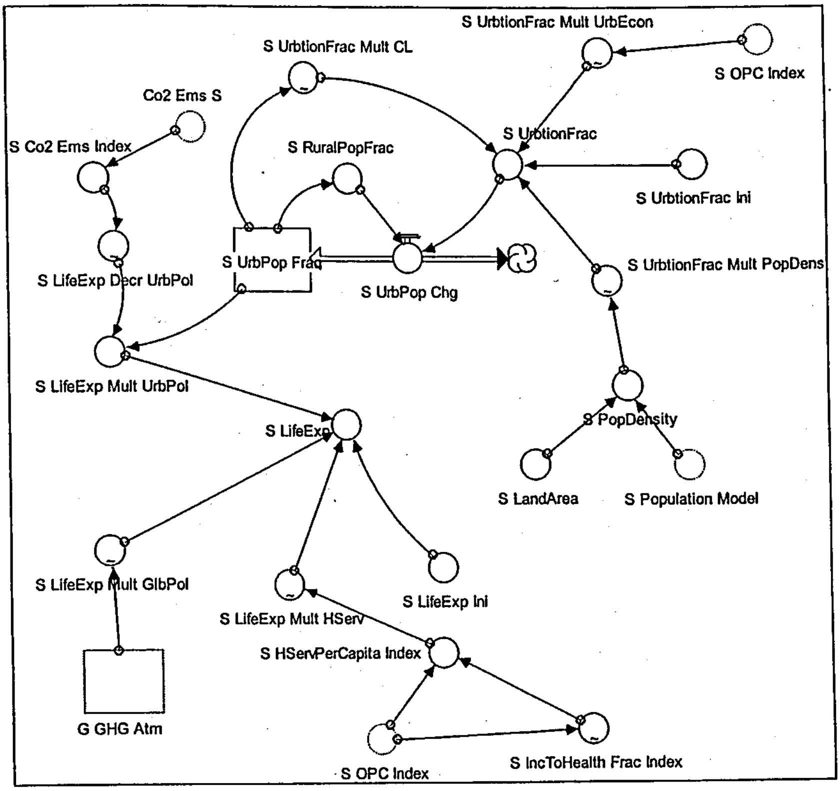


Figure 6.9. Stock-flow diagram of the structure related to average life expectancy

On the other hand, the second type of exposure may be defined as the pollution exposure due to being close to sources of pollution. At the aggregation level of this study, these sources are identified as the urban regions, where industrial activity is highly concentrated. The magnitude of effect in this type of exposure is estimated using the pollution emissions index in urban areas (*CO2_Ems_Index*) and the fraction of population living in these urban areas (*UrbPop_Frac*). In this estimation, emission rates of pollution are used instead of global pollution level, on purpose. As this type of exposure is mainly due to being close to the pollution source and highly dependent on the short-term pollution levels experienced at that region, instantaneous emission figures are evaluated to be a better indicator of that quantity. Although, *WORLD-3* contained an effect representing the negative effects of concentrated urban life, conceptualization and the related structure is totally different than the one used in this study.

The variable representing the fraction of urban population (*UrbPop_Frac*) is modeled as a stock variable, as seen in Figure 6.9 (instead of a converter as modeled in the

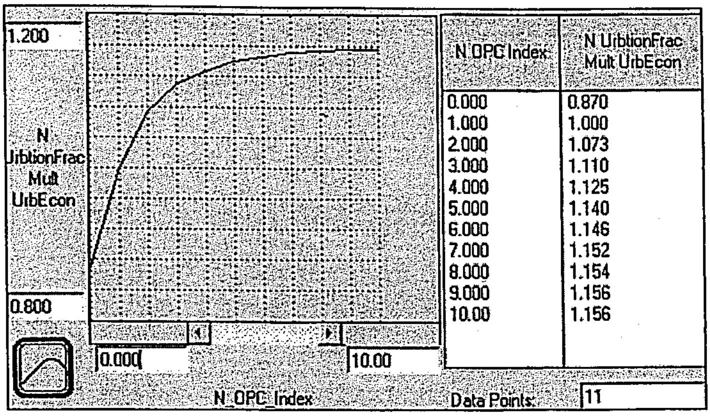
WORLD-3 model). This provides the generation of a smoother urbanization process, which seems to fit better to observed real urbanization dynamics. The fraction of rural population moving to urban areas (*UrbtionFrac*) is defined to be affected by the attractiveness of the urban areas due to increased economic activity (*UrbtionFrac_Mult_UrbEcon*) and the unattractiveness of rural areas due to increasing population density (*UrbtionFrac_Mult_PopDens*). Based on these assumptions, changes in the urban population fraction (*UrbPop_Chg*) are determined with the following equation set;

$$UrbPop\_Frac(t) = UrbPop\_Frac(t - dt) + (UrbPop\_Chg) \times dt \qquad (6.3)$$

$$UrbPop\_Chg = RuralPopFrac \times UrbtionFrac \qquad (6.4)$$

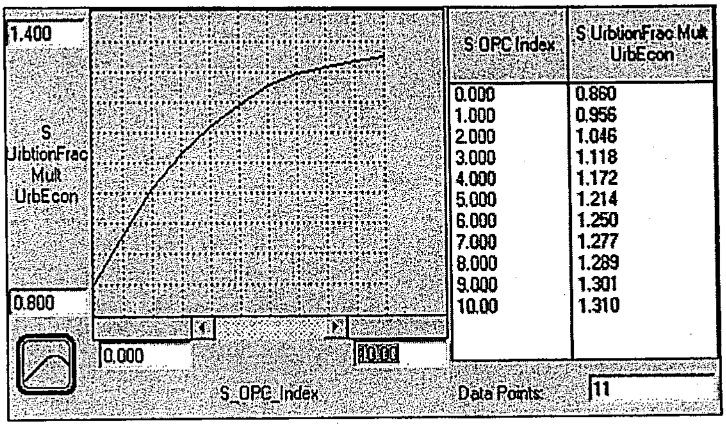
$$\begin{aligned} UrbtionFrac &= UrbtionFrac\_Ini \times UrbtionFrac\_Mult\_UrbEcon(OPC) \\ &\times UrbtionFrac\_Mult\_PopDens(PopDensity) \\ &\times UrbtionFrac\_Mult\_CL(UrbPop\_Frac) \end{aligned} \qquad (6.5)$$

Relying on the historical evidence, it is assumed that the intensity of the urban economic activity is highly correlated with output per capita (*OPC*) figure. Hence, effect of urban economic intensity on the urbanization process ($UrbtionFrac\_Mult\_UrbEcon$) is defined to be a function of output per capita (*OPC*). Although the general characteristics of the function is similar for both North and South, marginal return of increases in urban economy on urbanization process is assumed to be lower for North considering their urbanization level in 1975. Functions used for North and South are given in Figure 6.10 and Figure 6.11, respectively.



N OPC Index	N UrbtionFrac Mult UrbEcon
0.000	0.870
1.000	1.000
2.000	1.073
3.000	1.110
4.000	1.125
5.000	1.140
6.000	1.146
7.000	1.152
8.000	1.154
9.000	1.156
10.00	1.156

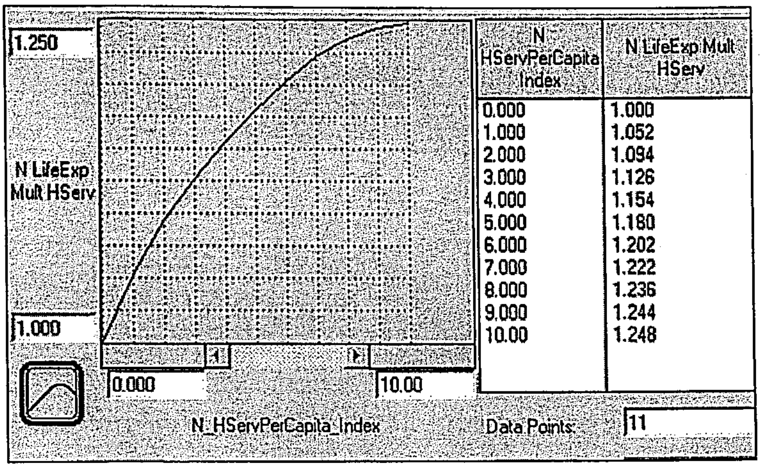
Figure 6.10. Effect of urban economic intensity on the urbanization process (North)



S OPC Index	S UrbtionFrac Mult UrbEcon
0.000	0.860
1.000	0.956
2.000	1.046
3.000	1.118
4.000	1.172
5.000	1.214
6.000	1.250
7.000	1.277
8.000	1.289
9.000	1.301
10.00	1.310

Figure 6.11. Effect of urban economic intensity on the urbanization process (South)

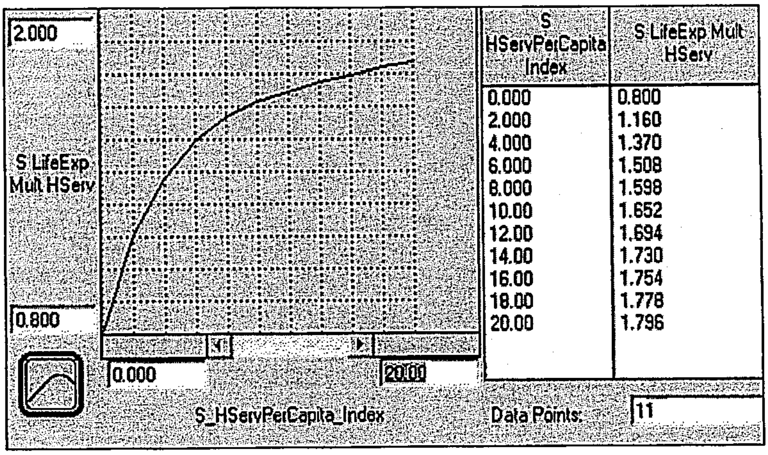
Apart from the urbanization process and related increase in exposure to pollution, the average life expectancy is dependent on the health services available per capita. A positive feedback relation is defined between the spending made on improving living and health conditions, and the life expectancy. Although there is limited reliable data regarding the health expenditures, especially for the South countries, the fraction of income allocated to improving health and living conditions increase as income per capita increases. In other words, income exceeding the needed amount for basic needs is used for improving such conditions. Thus, the spending made on health condition improvements is positively related with output per capita, which is used as the indicator of income per capita in this study, via two links. Assuming that spending fraction for health services is constant, as income per capita increases, income spent on health services increases. Additionally, fraction of income allocated to health services (*IncToHealth_Frac_Index*) is defined to be an increasing function of income per capita (*OPC_Index*).



N HServPerCapita Index	N LifeExp Mult HServ
0.000	1.000
1.000	1.052
2.000	1.094
3.000	1.126
4.000	1.154
5.000	1.180
6.000	1.202
7.000	1.222
8.000	1.236
9.000	1.244
10.00	1.248

Data Points: 11

Figure 6.12. Effect of health service per capita on life expectancy (North)



S HServPerCapita Index	S LifeExp Mult HServ
0.000	0.800
2.000	1.160
4.000	1.370
6.000	1.508
8.000	1.598
10.00	1.652
12.00	1.694
14.00	1.730
16.00	1.754
18.00	1.778
20.00	1.796

Data Points: 11

Figure 6.13. Effect of health service per capita on life expectancy (South)

As income spent on health services increases, life expectancy also increases. However, marginal return of income spent on such services is lower for the North, considering their current modern life style. On the other hand, a minimal increase in health services is assumed to result in a greater return in terms of life expectancy in South. Based on this assumption separate graphical functions are defined for North and South for the relation between the life expectancy and the health service spending per capita. Functions used for representing the relation between the health services per capita (*HServPerCapita_Index*) and its effect on average life expectancy (*LifeExp_Mult_HServ*) are given in Figure 6.12 and Figure 6.13.

<u>6.1.3.3. The Structure Related to Average Fertility per Woman.</u> Preserving the main logic in *World-3*, some minor modifications are done on the structure used for determining the fertility per woman. Simplified structure related to the fertility for woman is given in Figure 6.14.

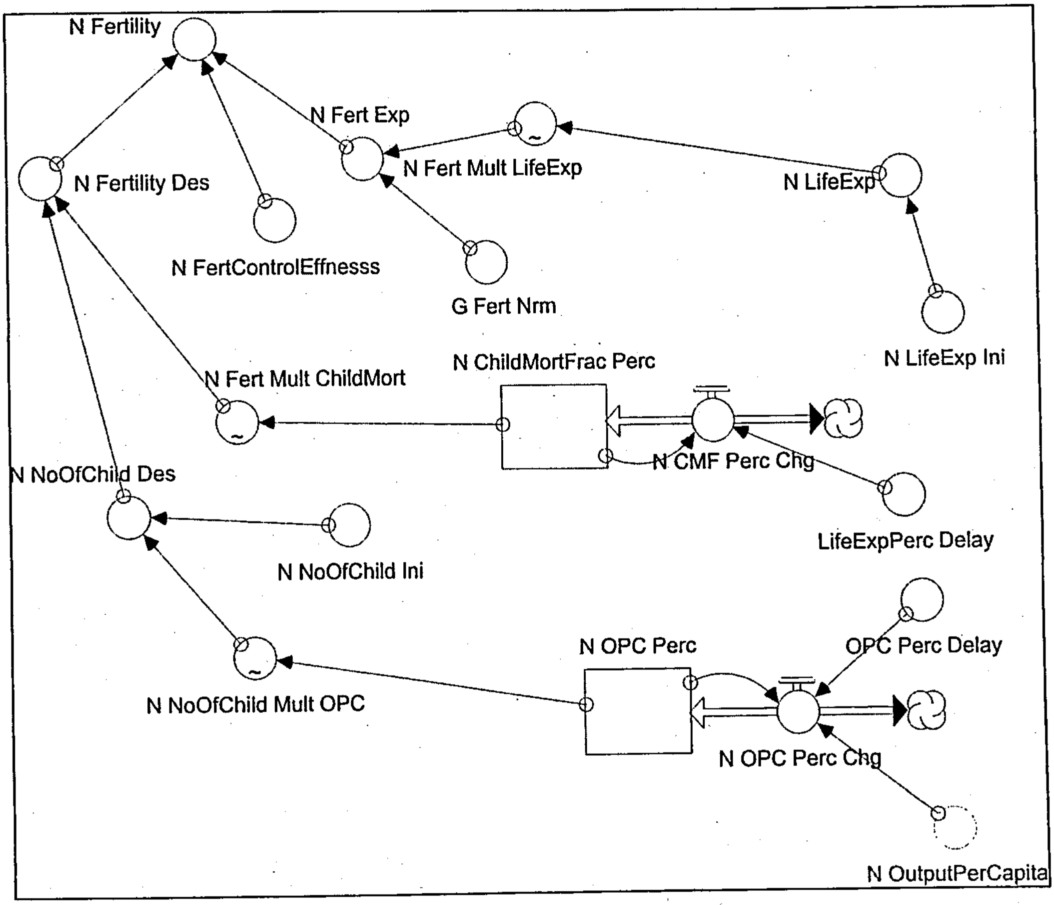


Figure 6.14. Stock-flow diagram of the structure related to fertility per woman

The number of births given by a woman during her reproductive period is defined to be the total fertility (*Fertility*) and it is a function of desired level (*Fertility_Des*) and natural level of fertility per woman (*Fert_Exp*), which occurs when no fertility control is adapted. Desired level of fertility (*Fertility_Des*) is defined to be a function of perceived income per capita in the society (*OPC_Perc*) and the perceived level of death probability of children before reaching the reproductive period (*ChildMortFrac_Perc*), or becoming adults.

On the other hand, natural level of fertility (*Fert_Exp*) is the maximum number of births that a woman can give with the current level of average life expectancy and given that no fertility control is employed. Total fertility (*Fertility*) is calculated as an expected value of these two fertility figures, using the fertility control effectiveness (*FertControlEffness*) as the probability of having exactly the desired fertility level.

Fertility control effectiveness is used as an exogenous parameter, and this parameter is manipulated for testing several scenarios. For the initial period, it is assumed to be close to 90 per cent for North, and to be around 70 per cent and gradually increasing for South.

Income per capita is represented by the output per capita figure, and its perceived level is generated with a simple information delay structure. In each period, perceived level of the variable is updated according to the actual level in that period. A very similar structure is employed for obtaining the perception regarding the death fractions experienced in the pre-reproductive sub-population.

6.1.4. Dynamics of the Population Sectors in Isolation

Isolated runs for the population sectors of North and South reveal two different population dynamics. As seen in Figure 6.15, North population has a decreasing rate of growth, whereas South population grows with an increasing rate of growth; like an exponential growth. Main factors underlying these dynamics can easily be identified by studying the age structures of these two populations.

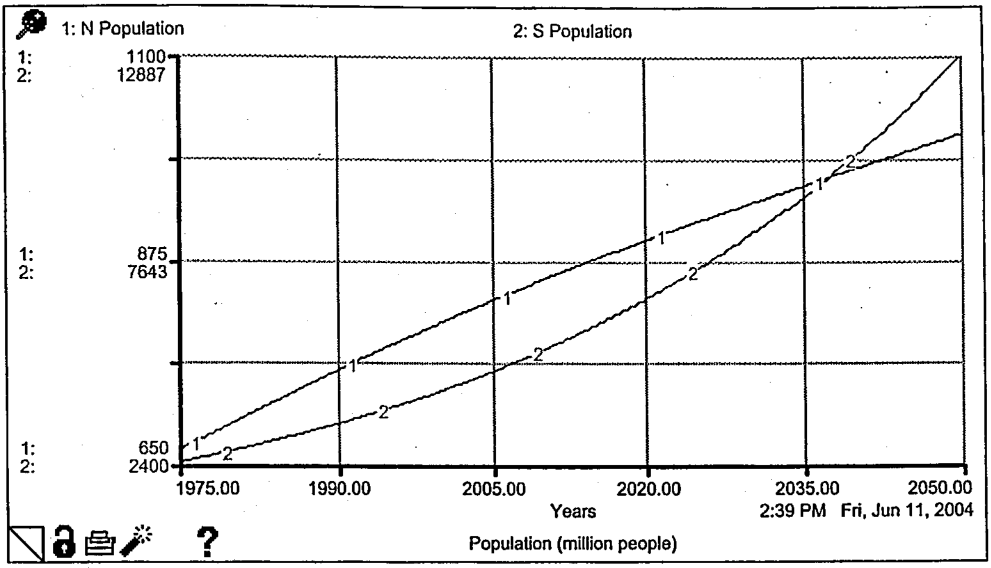


Figure 6.15. Population behaviors for North and South in isolated sector runs

In Figure 6.16, it is seen that post-reproductive group, being the least crowded group at the beginning, gradually becomes the most crowded one. While long life-expectancy allows this group to grow, low fertility values prevent high growth rates in pre-reproductive and reproductive groups. As the probability of death is highest for the oldest population group, growth of post-reproductive population results in an increase in the total deaths. Total births also increase, and this increase is directly connected to the growth rate experienced in reproductive population, which is a mild one. Although number of births is still more than deaths, the rate of growth in deaths seems to exceed rate of growth in births (see Figure 6.17). This results in a positive net rate of change for the population, which gradually decreases over time.

Dynamics of age groups in South population are given in Figure 6.18. High fertility rates coupled with the low life expectancy causes such a pattern. Due to high fertility rates, pre-reproductive and reproductive populations keep growing. On the other hand, low life expectancy values primarily increase the deaths from post-reproductive population group. In time this results in a decreasing relative share of post-reproductive group in total population. Considering that the major contribution to total deaths come from this age group, deaths decrease relative to increasing births caused by increasing reproductive group. As seen in Figure 6.19, discrepancy between deaths and births increase during the run and this implies an increasing positive rate of change for the total population. This property of rate of change results in the growth pattern for South population, seen in Figure 6.15.

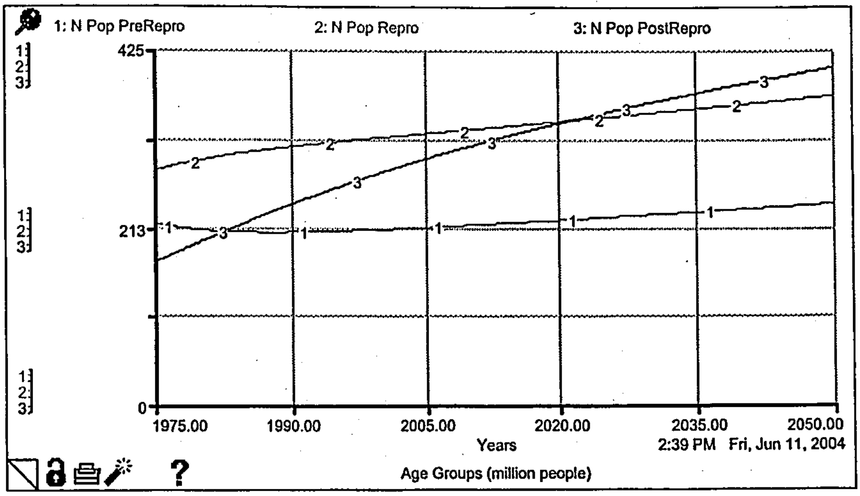


Figure 6.16. Population age groups for North in isolated sector runs

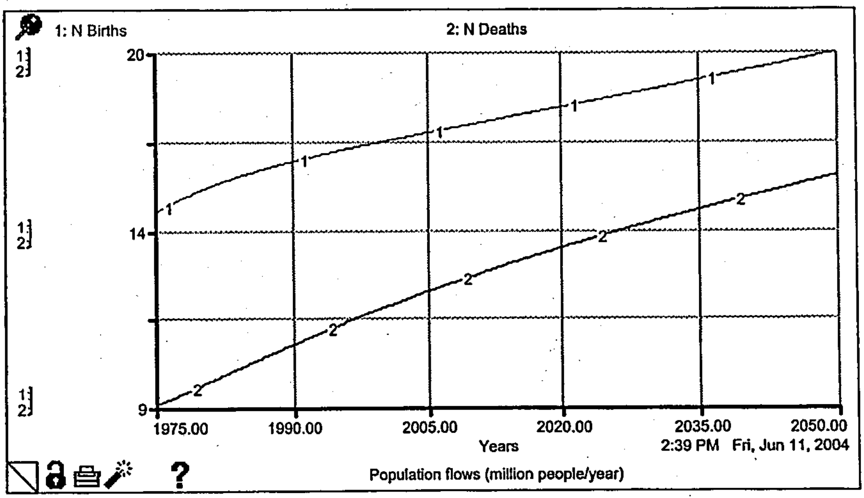


Figure 6.17. Birth and death flows of North population in isolated sector runs

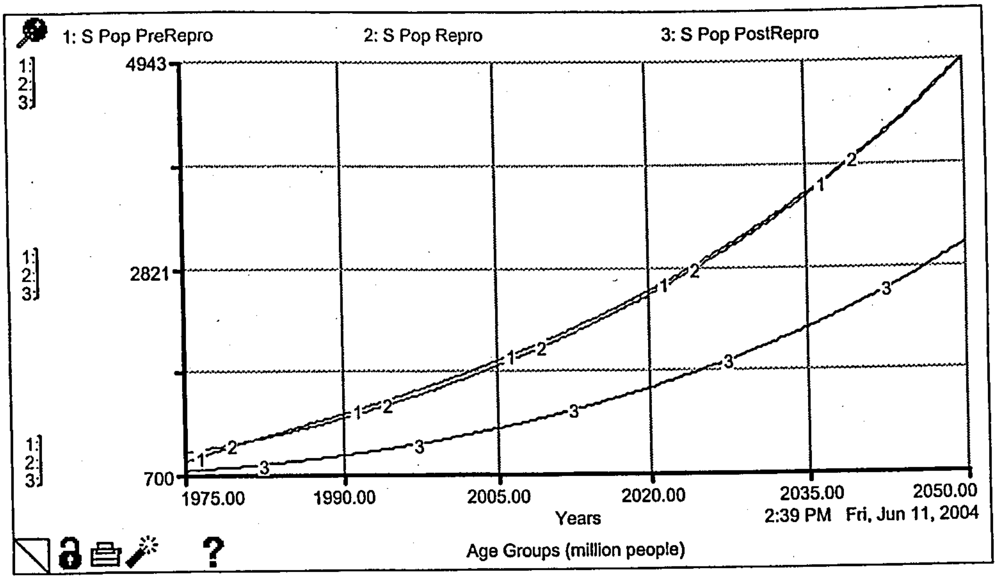


Figure 6.18. Population age groups for South in isolated sector runs

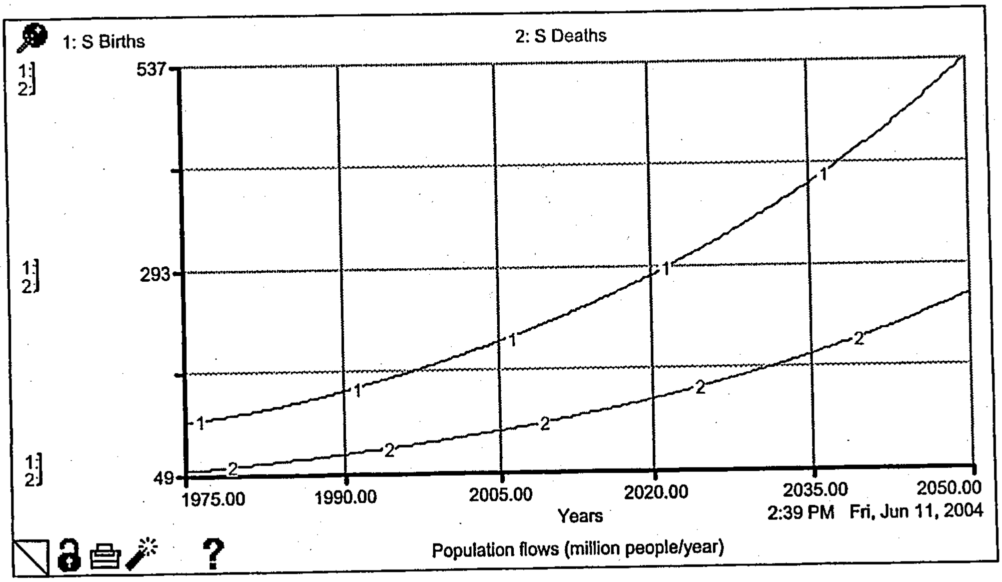


Figure 6.19. Birth and death flows of South population in isolated sector runs

6.2. Energy Resources Sector Group

6.2.1. Background Information

Although there are several forms of primary energy resources employed for energy generation, they all can be aggregated under two main categories; renewable and non-renewable energy resources. Among these two categories, non-renewables are the energy resources that have very long regeneration times compared to average human life. The most important members of this category are coal, oil and natural gas. Additionally, nuclear energy also can be classified under this category. This category of resources constitutes a remarkable portion, around 86 per cent, of global primary energy supply. On the other hand, renewable energy resources are the ones that have a short enough regeneration time that allows the substitution of the used amount, or the ones that have a continuous potential that can be used to generate energy. Altogether, renewables supply almost 14 per cent of global energy demand, traditional biomass being the most widely used type by 10.9 per cent (IEA, 2003a; IEA, 2003b).

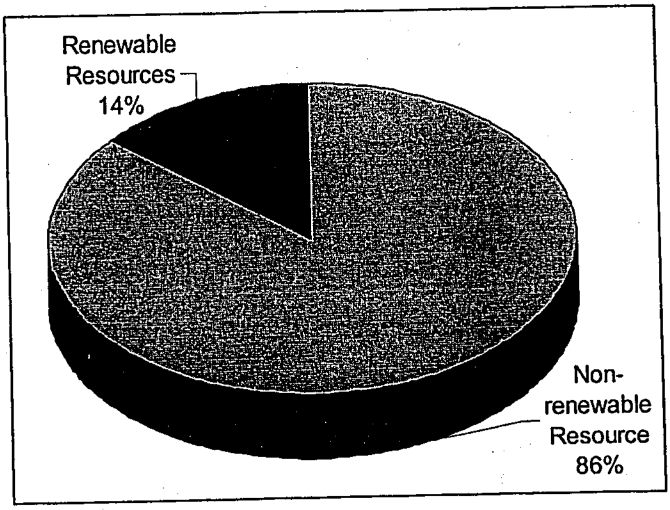


Figure 6.20. Shares of renewable and non-renewable resources in global primary energy supply

The finite reserves of the non-renewable energy resources coupled by the intense dependency of global economic activity on them make the transition from non-renewable resources to renewable ones a vital process. In the past 200 years, humanity experienced two such transitions. The first one was from wood to coal, and the second one was from coal to oil. However, there is an important difference between these former two and the expected transition that is probable to take place in the following century; the former two transitions were due to availability of better and cheaper resources, but in the current situation, coming transition is due to an expected shortage (Naill, 1992).

The opinions regarding the future availability of non-renewable resources and expectations regarding their price levels show a great variance. However, King Hubbert's theory on the pattern of oil production seems to have a wide acceptance (Hughes, 1999; Naill, 1992). According to his theory, production will follow a bell-shaped pattern and will have a long decline following a stationary peak period. In line with this theory, IEA indicates that global oil production will be experiencing its peak in the close future and a probable decline in global production should be expected in the first half of the 21st century (IEA, 2002b). Considering that oil is the most commonly used member of fossil fuel category, such a decline will probably trigger the transition to alternate energy resources.

Apart from the expected production patterns of fossil fuels, there are numerous estimates on when the global fossil fuel reserves will last. Depending on the methods employed and assumptions made, estimates regarding their availability range between 50 to several hundred years (UNDP *et al.*, 2000; UNDP, 2002). Although these figures are perceived as long enough to be optimistic by many, they should be evaluated considering the size and severity of the problem. It is clear that supply of fossil fuels will decline in the last portion of their life-cycle, which is estimated to be sometime in the 21st century. However, the most optimistic scenarios regarding global energy demand indicates a two-fold increase by 2050. In many others, expectations are even striking as a global energy demand 3.3 times the level experienced in year 2000 (UNDP *et al.*, 2000). This means a growing energy shortage in the sectors dependent on fossil fuels, which should be compensated from alternate resources. Considering the required infrastructure and end-user adaptation, it is estimated that such a transition can be completed in a range of 15-30 years.

When the issue is considered at a macro level, the complete transition from fossil to alternate resources may require around 50 to 75 years (UNDP *et al.*, 2000; Naill, 1992).

Despite the vagueness of the timing and speed of the transition from non-renewable resources to alternate renewable ones, a considerable amount of that transition will be experienced in the current century, and most likely in the first half of it. Additional to the perceived indicators of probable energy scarcity, there are several other factors that will affect the transition pattern and speed. First of them is the global environmental concerns regarding fossil fuel usage. Rise of such concerns as a consequence of climate change threat may boost up the transition from fossil fuels. This factor will be discussed in the pollution sector in more detail.

In the rise of concerns regarding the future availability of fossil fuels, there are several alternative energy resources being considered. The main characteristic of this category is that they are all renewable and environmental damage of these resources is considerably lower than the fossil fuels. In this wide range of renewable alternatives, two sub-categories are identified. The first sub-category includes traditional and new generation biomass, covering fuels like wood and animal disposals. The second category, which is also known as "new renewables" or "modern renewables", is composed of wind, solar, hydro and tidal energy. Altogether, renewables supply almost 14 per cent of global energy demand, traditional biomass being the most widely used by 10.9 per cent. Hydro power is the second most widely used renewable by 2.2 per cent and remaining new renewables supply only 0.5 per cent of total demand (IEA, 2003).

Traditional biomass, which is the most frequently used renewable energy resource, is mainly used for energy demand of households in developing countries. Despite certain improvements in the potential of this category, it does not seem to be an effective candidate that can substitute fossil fuels for the industrial and transportation related energy demand. On the other hand, modern renewables are employed on a very limited scale. They currently supply around 0.5 per cent of global energy demand. One of the two major drawbacks of these resources is their being expensive in energy generation compared to fossil fuels. Despite remarkable improvements in the cost of energy generation from these resources, they are still away from being competitive with fossil fuels. The second drawback is their reliability. These resources can be seen as perfect for households, but lot to be done in order to develop reliable means to generate more concentrated and consistent energy from these resources for industrial and transportation purposes (Farhar, 1996).

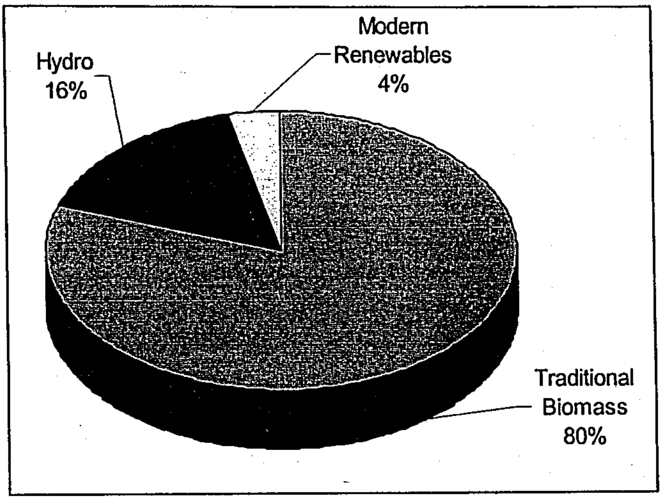


Figure 6.21. Share of individual resources in total renewable energy supply

Although there is a widely accepted theory that potential of the renewable resources exceed the global energy demand by several times (UNDP *et al.*, 2000; WEC, 2003), the energy generation methods using these resources are far from being economic. In this manner, due to lack of competition power of these resources with non-renewable resources and lack of required investment in infrastructure, the use of renewable resources is very limited in global scale. As a result, technological improvements, to be experienced in the following decades in energy generation from renewable resources, are vital in determining their potential for substituting non-renewable resources.

When the two different sets of countries are considered, it is evident that the pattern of the transition from non-renewable resources to renewable ones will probably have different paths. These paths include a range from a smooth and successful transition to a complete failure coupled with severe energy shortage. For the developed economies, or North, there is little doubt regarding the success of the transition. These economies use fossil fuels as the major energy resource for decades. As a consequence of technological improvements, North reduced the energy intensity of its economic activity, which in turn resulted in an economic growth outpacing the growth in energy demand (UNDP *et al.*, 2000). On the other hand technological base and investment power are the two very important facts regarding the developed economies' capability to develop infrastructure for energy generation from renewable resources (UNDP, 2002). These facts considered together supports such an assumption regarding the successful transition of North.

On the other hand, the situation is completely different on the South side. In almost every sustainable energy scenario, an important prerequisite for development of reliable energy systems is sufficient investment in research, development and distribution (UNDP, 2002). However, South block has deficiency in both technological base and investment power, which raises serious doubts. Coupled with that, current pattern in energy demand of South is very different than North. South has been going through the industrialization process and during this process it is very likely that demand for energy will grow exponentially. Currently fossil fuels supply almost 65 per cent of their total energy demand. In the following stages of their development, demand for fossil fuels will increase due to increasing fossil fuel share in total energy supply, increasing energy intensity of economic activity and economic growth. The following quotation from UNDP's report depicts similar concerns regarding energy problem of South:

> "A major challenge will be to find ways of meeting the growing demand for energy services in developing countries to support desired economic growth without incurring the adverse consequences associated with current patterns of energy use. To accomplish this, significant investment will be needed to supply the two to four fold increase in global primary energy projected in the World Energy Assessment over this century."
>
> "The strategies, and therefore the policies, needed to move toward a more sustainable future will for the most part need to be different in industrialized and developing countries."
>
> UNDP, 2002

As this probable shift from non-renewable to renewable energy resources seems to play a major role in the future economic development and as it seems to have differing characteristics for developed and developing economies, this sector of the model focuses on simulating the energy supply to the economic system and transition in the source of this supply.

6.2.2. Fundamental Approach and Assumptions

In the scope of this project, fossil fuels among non-renewable resources are identified to be the key input for the economic system. This choice was based on the relative importance of these resources compared to other resource inputs, and the currently observed trends.

The fraction of economic activity disturbed in an input scarcity case is obviously dependent on that scarce input and its substitutability. When the inputs for economic activity in the form of raw material and energy resource are considered, it is observed that variety of inputs used as energy resources is very limited, and this type of inputs are dominated by a single group of fuels at the global scale; fossil fuels. According to the WEC data published in *World Development Indicators 2003* report (World Bank, 2003a), fossil fuels are used for supplying nearly 90 per cent of global commercial energy demand in year 2001. For the same period, their share in primary energy supply is around 80 per cent, according to International Energy Agency data (IEA, 2003a). Apart from this usage intensity, installed energy infrastructures in transportation, electricity and industry are almost totally dependent on fossil fuels and this fact makes it hard to switch to an alternate energy source.

Additionally, there is currently no such efficient technology or resource that can be used as a substitute for fossil fuels. Despite extensive research conducted on alternative energy resources, it is projected that fossil fuels, supplying more that 80 per cent of current energy demand, will be the dominant energy supplier in the near future, as no competing technology or resource is visible in the following 30 years (IEA, 2003b).

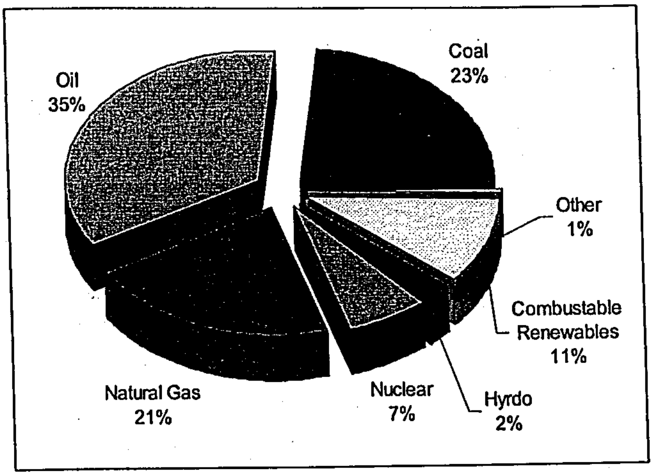


Figure 6.22. Global primary energy supply by source for the year 2001

On the other hand, the degree of transformation in the primary raw materials, especially metals, on average is considerably less than the transformation experienced in energy resources. This fact makes recycling of raw material viable, whereas recycling of energy resources experiencing chemical transformation (for example fossil fuels) is not possible. So in an optimist scenario, it may be assumed that recycling of raw materials could provide a solution, but a similar assumption will not be logical for energy resources even in such a scenario.

Although both forms of dependencies set a constraint for economic activity, points mentioned above demonstrate that the economic activity is seriously vulnerable to energy resource scarcities. As a result, it may be concluded that if economic activity will be constrained by input shortages in the following 50 years, it will be the energy resources limit that will be reached first. Standing on this conclusion, in this model raw material constraint is relaxed, and only the relation of economic system with environment regarding energy resources is considered. Such an approach to focus on the use of reserves of a few specific resources that are ultimately essential for the functioning of the economic system was also suggested by Muilerman and Blonk (2001), and Hughes (1999).

At an aggregate level, energy supplied directly to economic activity goes through two prior stages. First stage is the extraction or generation of the primary energy supplies.

This stage includes extracting the raw materials from the natural reserves, or generating energy from renewable resources. The second stage is converting these primary energy suppliers to usable fuels for the economic activity. Some typical examples of these usable fuels include electricity, gasoline and LPG. In this sector of the model, main focus is on the primary energy supply. The energy conversion process is considered to be an internal part of economic activity and it is assumed that energy resources are supplied in the form they are extracted from the environment, like coal, oil and gas (see Figure 6.23). As a result, in this model, energy demand of the economic activity is assumed to be supplied in the form of primary resources, not in their commercial forms that end-users actually consume.

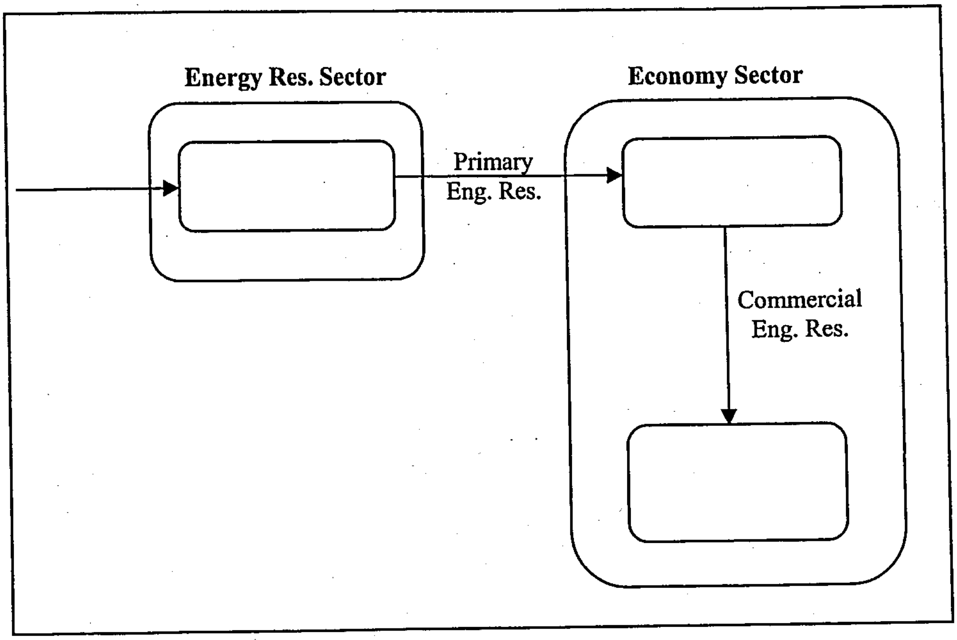


Figure 6.23. Flow of non-renewable energy resources to economic system

All energy resources are grouped under the non-renewable resources and the renewable resources categories. The total energy capacity of a country block is equal to the sum of its renewable and non-renewable energy capacities. While non-renewable energy capacity is dependent on the stock of physical non-renewable resources available, renewable energy capacity is determined by the capacity installed to generate energy from continuous sources as wind or water. Both categories are aggregated by using the oil equivalence values of individual resources, which is equal to the amount of oil required to generate energy equal to the amount generated with that particular energy resource.

As mentioned above, renewable energy capacity of a country block is dependent on the installed energy generation capacity. In defining this relation, it is assumed that potential amount of renewable energy that can be generated from the nature is far above the amounts that can be demanded by economic activity in the following five decades. Hence, bottleneck in renewable energy generation is assumed to be the infrastructure to convert this potential to energy. This assumption is based on the projections in the *World Energy Assessment* report regarding energy demand and potential of renewable energy resources (UNDP *et al.*, 2000).

Energy demand of each block is determined by the output capacity of the economy and the energy intensity of that block's economic activity. The time-series data for the energy intensity per output demonstrate a significant decrease for all three country blocks. Interestingly, energy intensities of these three blocks converge to a common value of approximately 0.20 ktoe per million dollars worth output (see Figure 6.24). However, the analysis conducted failed to relate this trend with the endogenously modeled factors and mechanisms. Hence, energy intensities of country blocks are introduced as exogenous function. Values are estimated using the actual time-series data for the last 25 years.

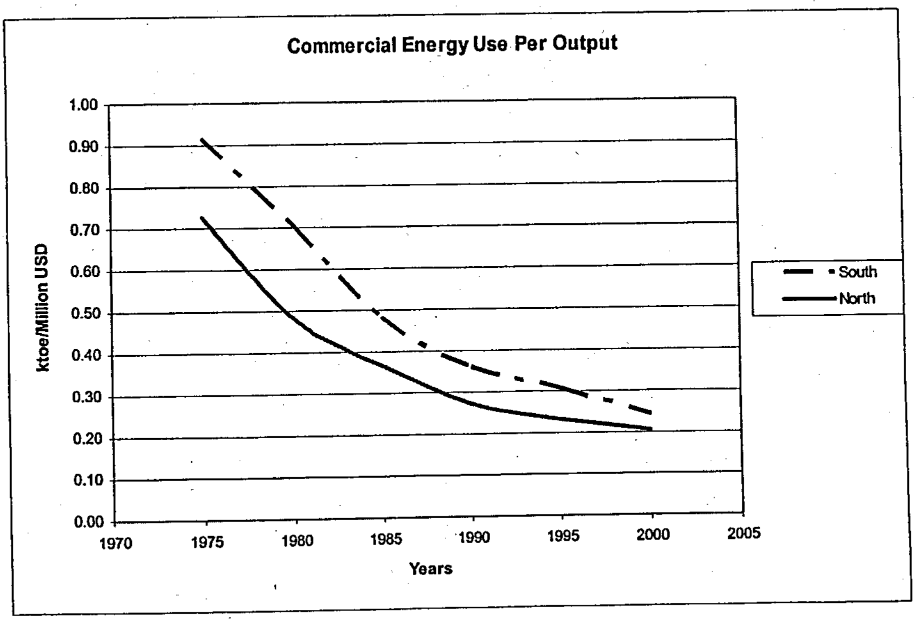


Figure 6.24. Actual time-series data for energy used per output for North and South

One of the fundamental assumptions of this study regarding economic system regarding market mechanism and factor prices has also implications on the energy resources sector. As the time horizon of the model, 75 years, is very long compared to the reaction times of market economy, short-term price adjustment mechanisms of market economy are neglected and equilibrium is assumed to prevail between demand and supply throughout the time horizon. Based on this approach, it is assumed that the price of energy resources will be determined by cost of obtaining them rather than short term supply-demand interactions. In the long run, the amount of capital required for obtaining a particular resource is used as the dominant factor in the resource cost, as both extraction of non-renewable energy resources and generation of renewable energy are capital-intensive activities. Reciprocal of this price indicator, energy generated per capital allocated to energy generation is assumed to be dominated by technological progress for renewable energy generation. On the other hand, amount of non-renewable energy resource that can be extracted per capital is set to be dependent on fraction of non-renewable resources reserves remaining. In defining this relation, it is assumed that easily accessible reserves with rich ores will be exploited first and remaining reserves will be the ones hard to reach, explore and extract (Meadows *et al.*, 1974).

The amount of reserves owned by individual country blocks is determined by using the data about currently known reserves and yearly production rates. According to the WEC statement, 80 per cent of world oil and natural gas liquids (NGL) production come from 20 countries, and 90 per cent of world oil and NGL reserves are located in 15 countries (WEC, 2001). Among these top 20 producers, none of them is from South block and only two of them are from North block. Additionally, domestic demands of these two North producers are above their yearly production, so they are also net importers of oil and NGL. Based on these facts, it is observed that none of the countries included in North or South blocks is a net exporter of these primary energy resources. Hence, Rest-of-the-World is concluded to be the country block that supplies the non-renewable energy demanded by both North and South blocks. Global reserves of non-renewable energy resources are assumed to be totally located in to Rest-of-the-World (*RoW*) block. As a result, energy sector of the Rest-of-the-World is modeled to include non-renewable energy resources, reserves and extraction mechanisms.

6.2.3. Description of the Structure

The sector group related to energy resources is composed of three main sectors. Two of them are almost identical, and are built for North and South in order to represent the mechanisms responsible for supplying the energy demanded by the economic activity sectors. Third sector belongs to RoW block, and is mainly responsible for the non-renewable resource production and global non-renewable resource supply. In determining the dynamics related to energy, these three core sectors interact with a set of four other sectors related to economic activity and global pollution. A high-level representation of the interactions between these seven sectors is given in Figure 6.25.

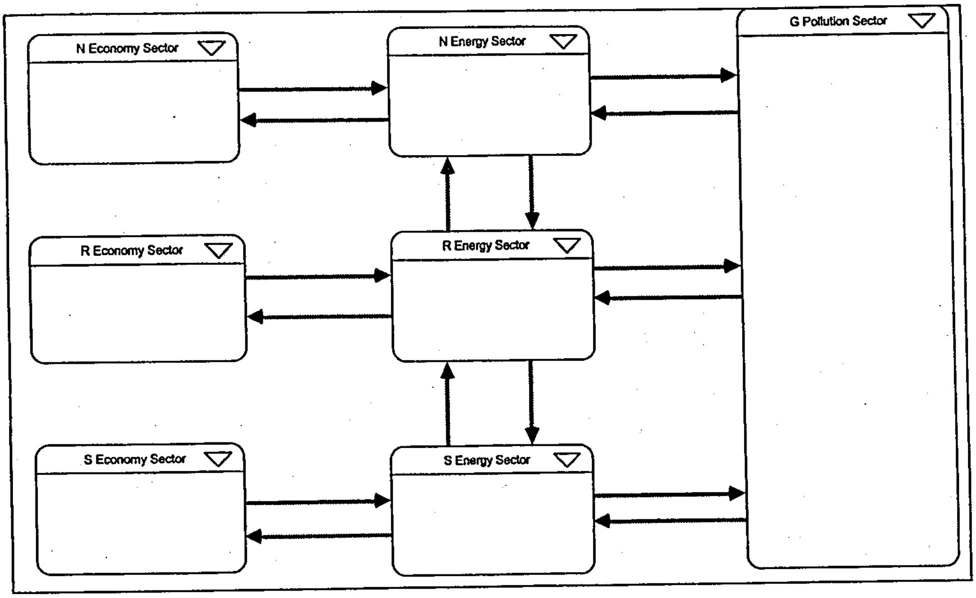


Figure 6.25. Interrelationships between energy-related sectors

Briefly, energy demands from individual economic activity sectors are directed to corresponding energy sectors. This demand is equal to the amount of energy required for realization of output capacity of the economic system, and it is a function of total output capacity of the installed capital and the average energy intensity of economic activity. Total output capacity of the installed capital refers to the maximum amount of economic output that can be generated with the current capital, given that there is enough energy supply. On the other hand, energy intensity refers to energy required in order to generate 1 international dollar worth economic output. Energy intensity is used as an exogenous parameter in the model, as explained before.

The energy demands received from economic activity sectors are allocated among renewable and non-renewable resources and satisfied from these sources in the energy sectors, as long as related capacities permits. As some portion of non-renewable energy resources' stocks are depleted for satisfying the energy demand, country blocks demand non-renewable resources from RoW block in order to replenish their stocks. These orders for non-renewable resources constitute the global resource demand.

The global pollution sector is responsible for the dynamics of greenhouse gas (GHG) emissions and their atmospheric levels. The level of GHG emission is determined by the non-renewable energy resource usage rate in individual energy sectors. The feedback from pollution sector to energy sectors regarding the global pollution level affects the allocation of energy demand among two alternative sources: renewable and non-renewable resources.

The sectors constructed for representing the energy supply mechanisms of North and South are almost identical. This structure, given in Figure 6.26, is composed of four sub-structures. These structures are responsible for allocating the energy demand among alternate energy resources, adjustment for non-renewable energy resources stocks, capacity building for renewable energy generation and technological improvement in renewable energy generation technology.

Variables used in these two sectors are presented in Appendix B with their brief descriptions and units.

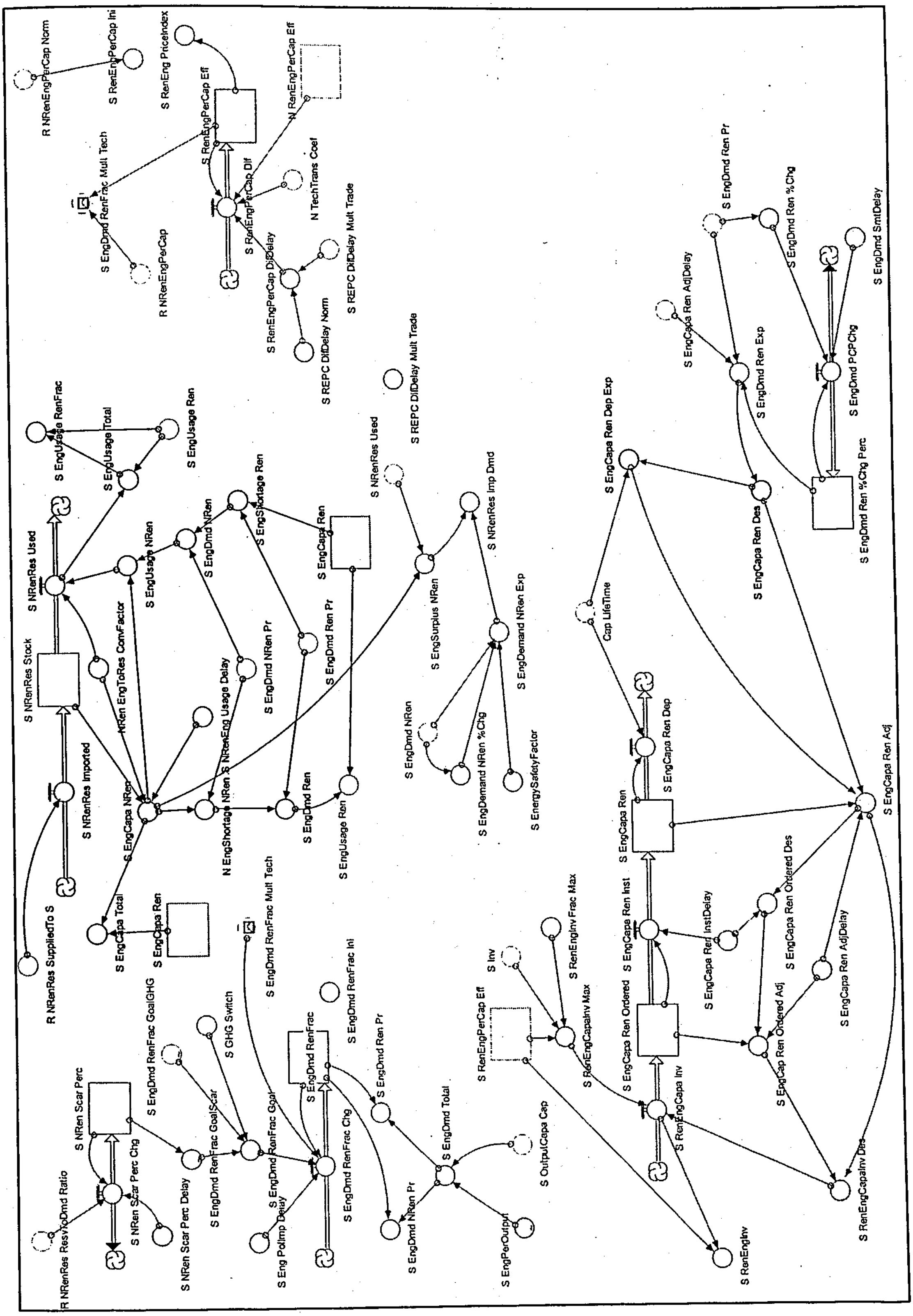


Figure 6.26. Stock-flow diagram of the energy sector of South

On the other hand, energy sector of RoW block is significantly different from the ones belonging to other two blocks. This sector, given in Figure 6.27, includes the structure related to the global non-renewable energy reserves and their exploitation, as well as the structure related to satisfaction of resource demands coming from North, South and RoW blocks. These structures will also be explained in detail in the following sections. Variables used in the energy sector of RoW block are also explained in Appendix B.

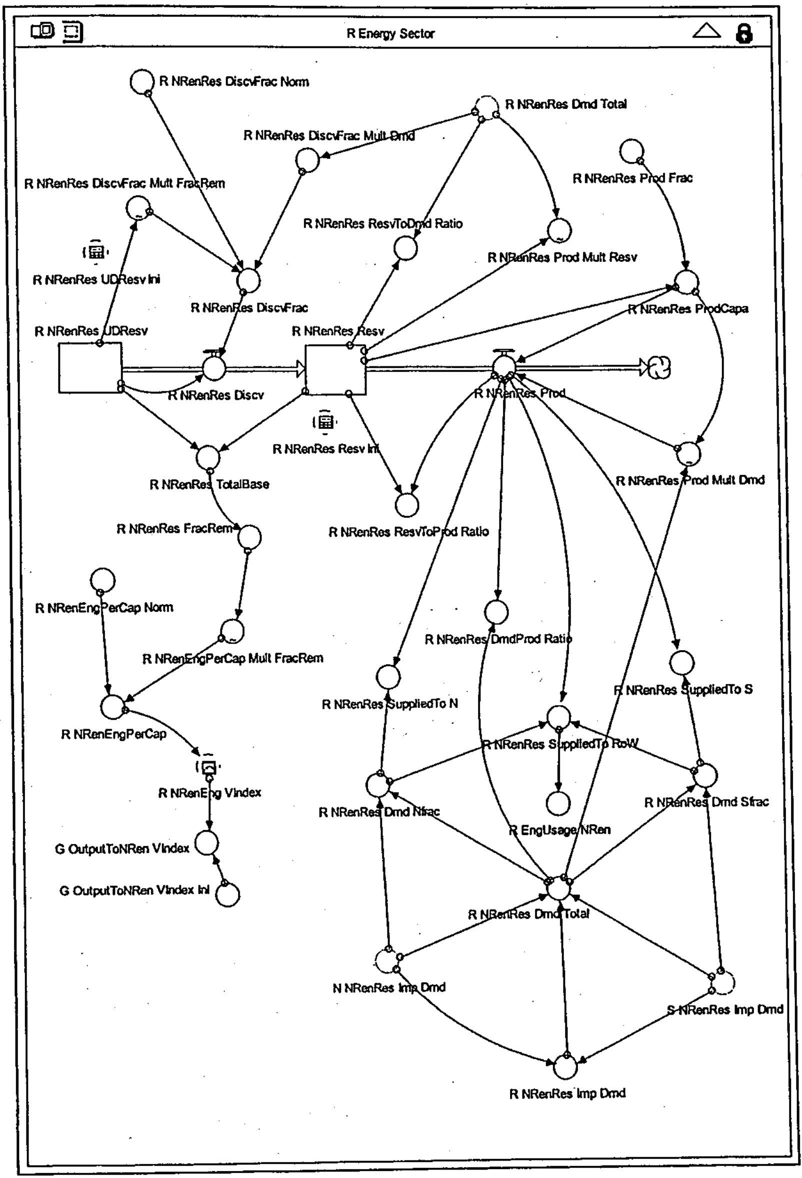


Figure 6.27. Stock-flow diagram of the energy sector of RoW

6.2.3.1. The Structure Related to Allocation of Energy Demand among Alternate Energy Resources. As mentioned before, the model covers two broad alternatives for energy generation; using non-renewable resources or generating by renewable methods. So determining the fraction of demand allocated to one of these alternatives is sufficient to determine the energy demand for the other, given the total energy demand. Hence, only the fraction of energy demand directed to renewable energy resources is modeled explicitly, and the fraction directed to non-renewable resources is determined indirectly.

The fraction of energy demand directed to renewable alternatives is considered to be dependent on long-term policies, rather than short term supply-demand fluctuations. It is evident that formation of a renewable energy market, on the global scale, is dependent upon the long-term energy policies of governments and multi-national energy corporations. It is assumed that these long-term policies are significantly affected by factors like decreasing non-renewable resources availability, increased public awareness regarding hidden costs of fossil fuels, increasing impacts of GHG accumulation in the atmosphere, and competitiveness of alternative resources against non-renewables.

In the model, the desired fraction of renewable resource usage is distinguished from actual fraction. As a result of perceived level of non-renewable resource scarcity risk and global pollution, a goal for renewable resource usage is set out. Following this goal setting, demand for renewable resources is shifted in-line with these goals. This shift may be done by subsidies, developing public awareness, and some other means. However, none of these mechanisms are included in this model, and it is just assumed that these goals result in a shift in the energy demand between alternative resources according to the goals set. While perceived danger related to resource scarcity or GHG levels change the target level of renewable resource usage, technological competitiveness of energy generation methods from these resources speed up the process of demand generation in the direction of these goals.

As indicated above two factors are identified to affect the future share of renewable resources in energy supply. Figure 6.28 provides a brief causal-loop diagram that demonstrates the causal mechanisms related to these two factors. Increasing non-renewable resource usage increases GHG level in the atmosphere. Perception of this increase after a delay increases the target level of renewable resource usage, and as a consequence of changing demand allocation due to this changed goal, usage rate of non-renewables decreases. This is the pollution related balancing feedback loop for non-renewable resources usage.

Second balancing feedback loop is related to the availability of reserves. As non-renewable resources usage continues reserve-demand ratio decreases due to depletion of the reserves. The decrease in this scarcity indicator results in an increase in target level of renewable resource usage, and this change triggers a decrease in the non-renewable resources usage by shifting some portion of energy demand to renewable resources. Both of these balancing feedback loops are demonstrated in the causal-loop diagram in Figure 6.28, and they are marked with a "-" sign.

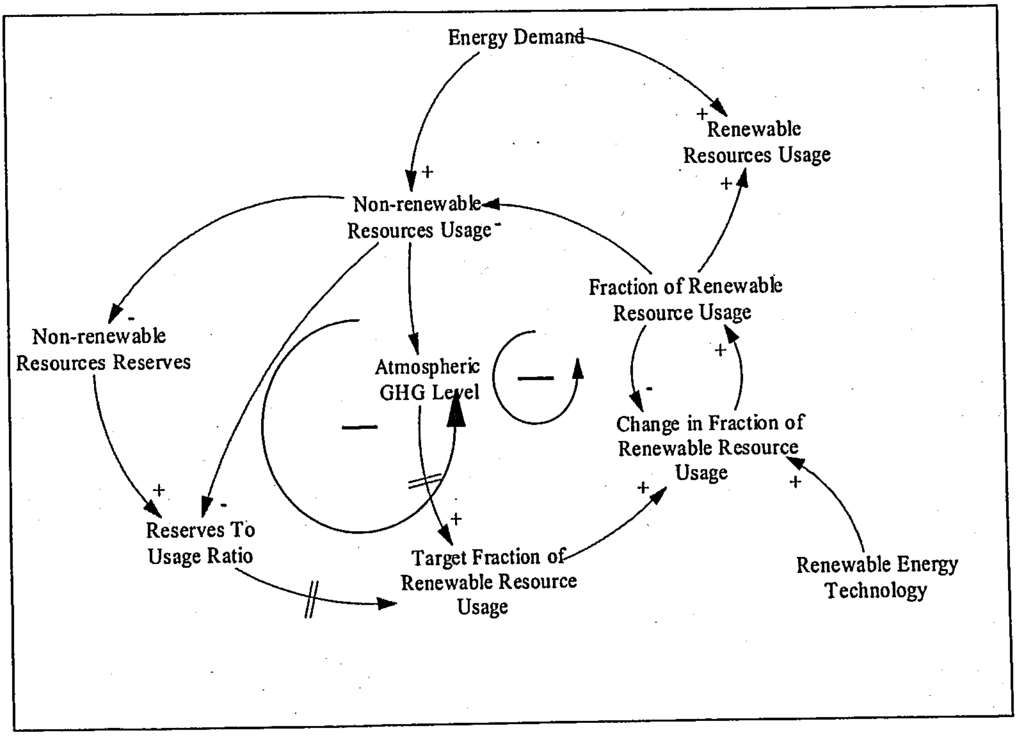


Figure 6.28. Basic causal relationships in the allocation of energy demand

To be more specific about the structure used for setting the target level for fraction of energy demand directed to renewable resources, two separate target levels are determined based on two separate indicators. One of these goals is related to the scarcity risk of currently used non-renewable resources, and manipulated by the perceived reserve-demand ratio. This ratio is commonly used for forecasts regarding future availability of mineral resources and gives the ratio of yearly demand to total known reserves. In our model, this goal is set as a reaction to the perceived level of reserve-demand ratio. For this reason, an information delay structure is introduced in order represent the perception delay of this scarcity indicator. Simplified structure is given in Figure 6.29.

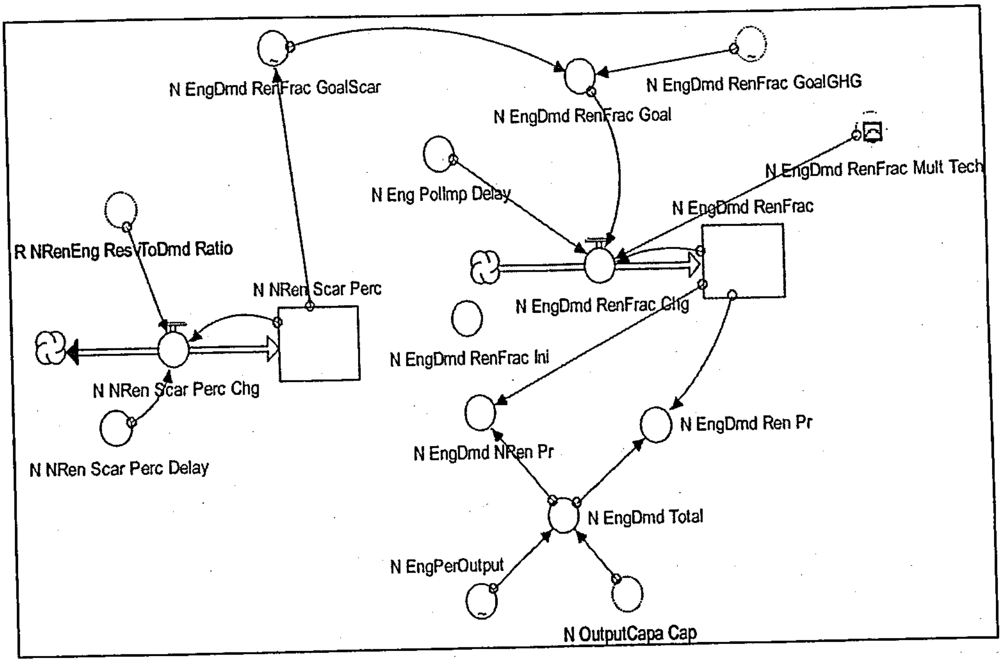
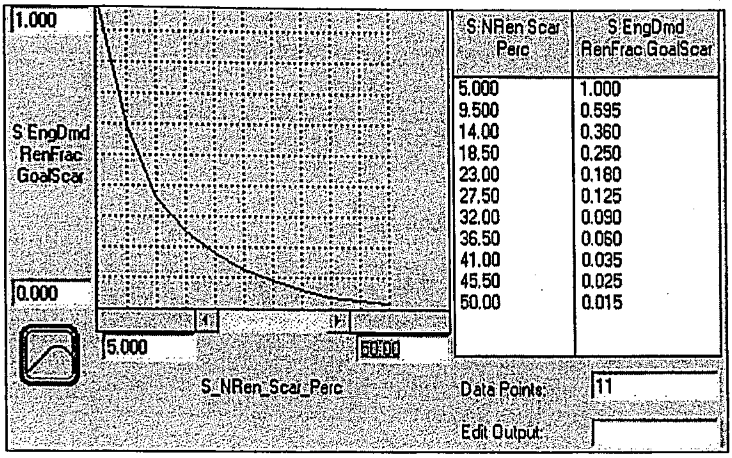


Figure 6.29. The structure related to determination of fraction of renewables in total energy demand

The relation between the perceived level of reserve-demand ratio (*NRen_Scar_Perc*), and the desired level of energy demand fraction directed to renewable resources (*EngDmd_RenFrac_GoalScar*) is defined as a non-linear function.

$$EngDmd\_RenFrac\_GoalScar = f(NRen\_Scar\_Perc), \text{ where} \qquad (6.6)$$

f(NRen_Scar_Perc) is given in Figure 6.30.



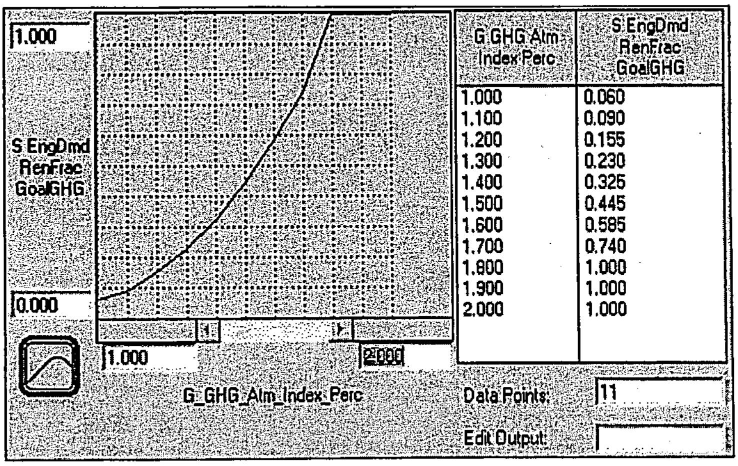
S NRen Scar Perc	S EngDmd RenFrac GoalScar
5.000	1.000
9.500	0.595
14.00	0.360
18.50	0.250
23.00	0.180
27.50	0.125
32.00	0.090
36.50	0.060
41.00	0.035
45.50	0.025
50.00	0.015

Data Points: 11

Edit Output:

Figure 6.30. Target level for fraction of energy demand directed to renewables as a function of perceived scarcity risk indicator

The second goal level for fraction of energy demand directed to renewables is manipulated by the CO_2 accumulation level in the atmosphere. Currently 80 per cent of global CO_2 emissions are due to non-renewable energy resources (IPCC, 2001). Based on that, it is assumed that increased atmospheric CO_2 levels will induce a shift away from non-renewables. The graphical function in Figure 6.31 is used to define the relation between the global atmospheric CO_2 accumulation and the goal level for fraction of energy demand directed to renewables.



G GHG Atm Index Perc	S EngDmd RenFrac GoalGHG
1.000	0.060
1.100	0.090
1.200	0.155
1.300	0.230
1.400	0.325
1.500	0.445
1.600	0.585
1.700	0.740
1.800	1.000
1.900	1.000
2.000	1.000

Data Points: 11

Edit Output:

Figure 6.31. Target level for fraction of energy demand directed to renewables as a function for perceived atmospheric GHG level

Among these target levels, the maximum of the two is assumed to dominate the renewable energy policy of a country block. This dominant policy is realized after a delay, and in order to capture this behavior, a simple first-order information delay structure is used for determining the renewable energy demand fraction (*EngDmd_RenFrac*). Additionally, an effect variable representing the effect of changing competitiveness of renewables against non-renewables is also introduced (*EngDmd_RenFrac_Mult_Tech*). In doing so, it is assumed that increased renewable energy technology may decrease the relative cost of renewables, and as a result it may speed up the target realization process. The input used for this effect is the ratio of energy obtained per capital in renewable energy generation to this variable's counterpart for non-renewable energy generation. As this variable is employed as an indicator of reciprocal of cost, such an input is accepted as a representative of the cost competitiveness of renewables against non-renewables.

6.2.3.2. The Structure Related to Adjustment for Non-Renewable Energy Resource Stocks. A stock variable is defined for all country blocks in order to track the amount of non-renewable energy resources available to be used for energy generation. This stock (*NRenRes_Stock*) is manipulated by an outflow of resource usage for energy generation (*NRenRes_Used*) and an inflow representing the imports from non-renewable energy resources exporting countries, included in the RoW block (*NRenRes_Imported*).

As in the case of a simple inventory problem, the orders for non-renewable resource replenishment are placed to RoW block (*NRenRes_Imp_Dmd*), based on the current inventory and desired stock levels. The desired level of non-renewable resources stock is set to be a variable target, instead of a fixed one. In each time period, a new desired level is determined using a simple forecasting procedure. By using the recent trend (*EngDemand_NRen_%Chg*) and the current value of the demand (*EngDmd_NRen*), a forecast for the next period's non-renewable resource demand is generated (*EngDemand_NRen_Exp*). Then, desired level of stock is set to be equal to this expected demand value multiplied by a safety factor for unexpected increases. Refer to the Figure 6.32 for a simplified stock-flow diagram of the related structure.

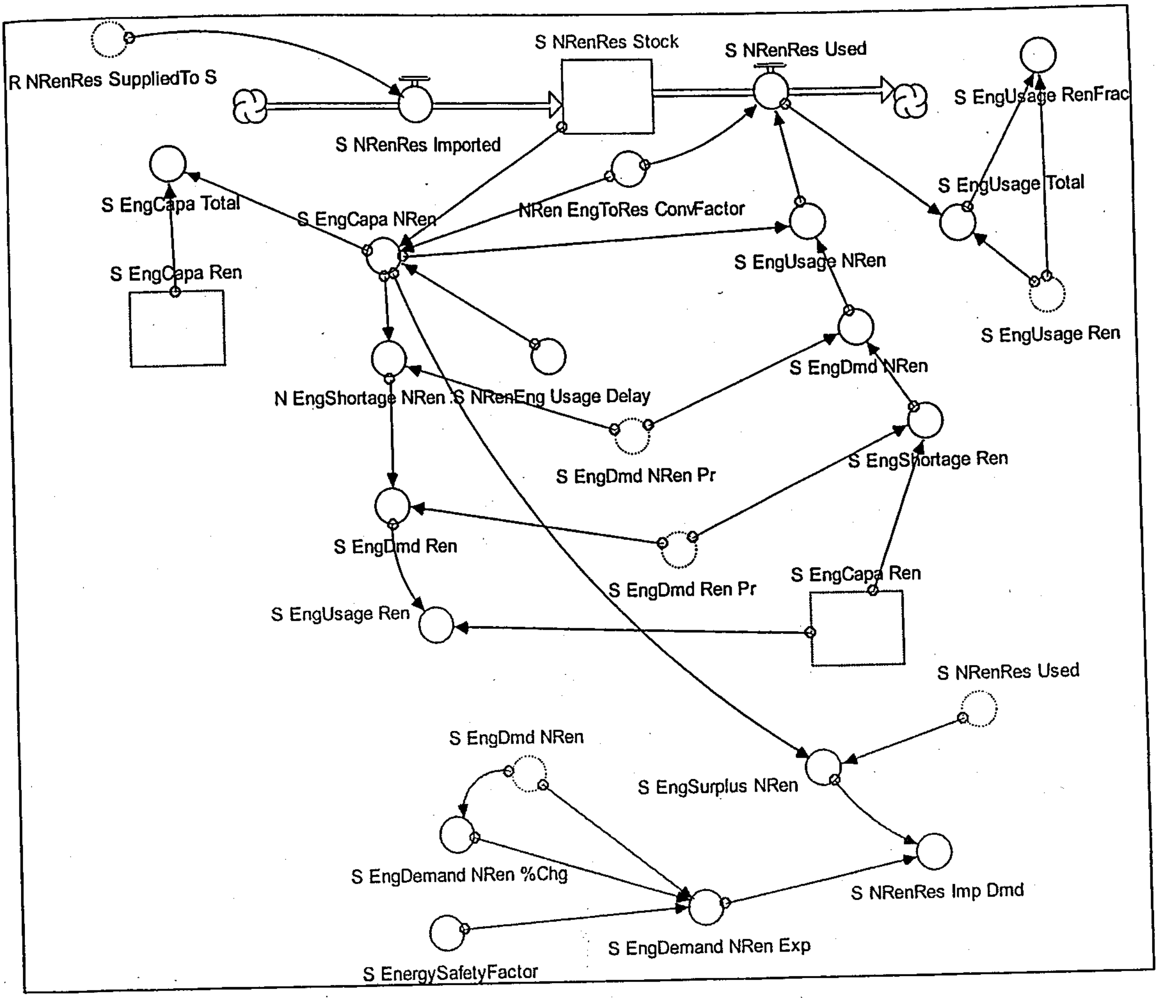


Figure 6.32. The structure related to non-renewable resource usage and replenishment

6.2.3.3. The Structure Related to Capacity Building for Renewable Energy Generation.

Local capacity of renewable energy resources is determined by the amount of investment done on renewable energy infrastructure and the technological level employed in generating energy from these resources. Investment is directly driven by the difference in the demand and the current capacity of the installed infrastructure. It is assumed that the only motivation of the market is to satisfy the demand, and market economy is assumed not to have any motivation towards investing in renewable energy infrastructure with environmental concerns in the lack of demand, which seems to be a quite realistic assumption.

Installed capacity for energy generation from renewable resources is represented using a simple capacity investment structure. The orders for new capacity are given by considering the current level of capacity, the desired level of capacity and the capacity ordered but not installed. These orders are installed and become operational after a certain installation delay. Finally, some portion of the installed capacity is lost due to depreciation in time.

The desired capacity for energy generation from renewable resources is calculated using the current demand and the perceived fractional growth rate of the demand (*EngDmd_Ren_Trd_Perc*). Instead of using the instantaneous growth fraction (*EngDmd_Ren_Trd*), a value smoothed with a first-order information delay is used in the calculations. This structure seems to be a better representative of the real life delay in the perception of the data. Using this smoothed growth fraction (*EngDmd_Ren_Trd_Perc*), current demand level (*EngDmd_Ren*) and the capacity adjustment time (*EngCapa_Ren_AdjDelay*), an expected renewable energy demand (*EngDmd_Ren_Exp*) is calculated. In generating the demand forecasts, it is assumed that demand grows exponentially. The formulation used is as follows;

$$\begin{aligned}&EngDmd\_Ren\_Trd\_Perc(t) = EngDmd\_Ren\_Trd\_Perc(t-dt)\\&+\frac{EngDmd\_Ren\_Trd(t)-(EngDmd\_Ren\_Trd\_Perc(t)}{EngDmd\_SmtDelay}\end{aligned} \tag{6.7}$$

$$EngDmd\_Ren\_Exp = (EngDmd\_Ren \times (1 + EngDmd\_Ren\_Trd\_Perc))^{S\_EngCapa\_Ren\_AdjDelay} \tag{6.8}$$

The desired level of energy generation capacity is assumed to be equal to this expected demand.

The desired capacity adjustment (*EngCapa_Ren_Adj*), or desired capacity investment is determined using the desired (*EngCapa_Ren_Des*), current (*EngCapa_Ren*) and ordered (*EngCapa_Ren_Ordered*) capacity. The structure used for capacity ordering and accumulation is very similar to inventory structures with supply-line employed in inventory problems. While expected depreciation represents the expected sales in the inventory problem, desired capacity is representative of the desired inventory level. Finally, capacity ordered can be considered as the supply-line in the inventory problem. Using this analogy, the commonly used anchoring and adjustment rule is employed for determining new capacity orders. In this rule, desired capacity order is composed of expected capacity loss, an adjustment term proportional to the difference between desired and current capacity level and a similar adjustment term for the ordered capacity stock (Özevin, 1999).

Realization of the desired investment is constrained by the funds and capital available for investment in the whole economy, as it is not logical to have investment to energy sector independent of the investment power of the whole economic system. In the aggregation level used in the model, it is unfortunately not possible to identify the fraction of capital available for energy investment endogenously. Hence, an exogenous parameter is introduced to define the maximum fraction of an economy's investment power that can be directed to energy sector (*RenEngInv_Frac_Max*). For optimistic scenarios, this parameter is set to be as high as 50 per cent. However, for the regular cases it is assumed that a logical ceiling will be around 30 per cent. Historical values related to fraction of energy share in investment indicates that even in the exceptional countries making extensive energy investment this fraction does not exceed 40 per cent (UNDP *et al.*, 2000). Using this variable, the maximum level of renewable energy investment (*RenEngCapaInv_Max*) is calculated and this maximum level is used as a constraint for desired renewable energy capacity investment (*RenEngCapaInv_Des*) in order to calculate the realized level of capacity investment (*RenEngCapaInv*).

For the base run of the model, capacity adjustment delay is set to be 5 years, and capacity installation delay is set to 15 years. In setting the 15 year delay for capacity installation, it is considering that capacity installation includes building the facilities to generate energy, building the networks to distribute it and end-user adaptation.

The structure related to renewable energy capacity is given in Figure 6.33.

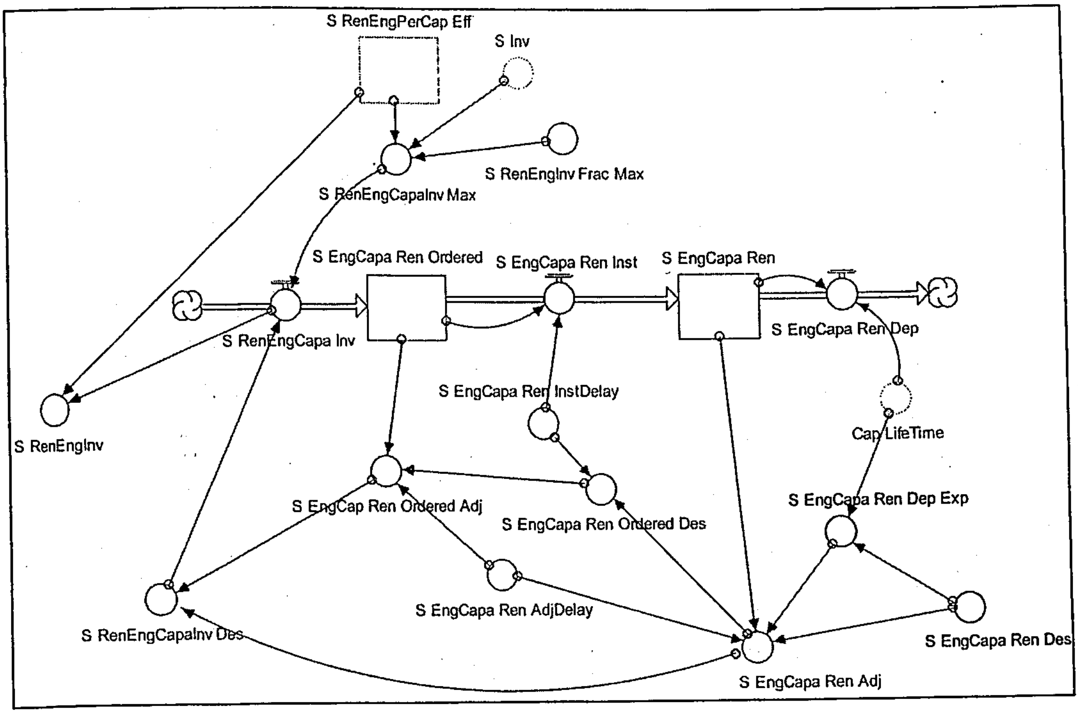


Figure 6.33. The structure related to renewable energy capacity

<u>6.2.3.4. The Structure Related to Improvement in Renewable Energy Generation Technology.</u> There is no separate variable used to quantify technological level employed in energy generation from renewable resources. Instead, technology is assumed to be embedded in the capital used in the process, and energy productivity of the capital (energy generated per capital in unit time) is used as the indicator of the embedded technology. Although productivity is also affected by other factors like labor skill, it is assumed that capital technology dominates due to the capital intensive nature of energy industry.

The technological improvement structures used for North and South blocks are not identical. In the model, North is assumed to be the technology leader and mainly responsible for the major improvements in the technology used in renewable energy generation. On the other hand, South is assumed to be incapable of making significant improvements by itself. So, South is defined to be a technology adaptor block, which adopts the technology developed by North after a certain delay.

In the technological improvement structure of North, two separate capital productivity values are defined. One of these (*RenEngPerCap*) represents the capital productivity that can be attained by utilizing the top level technology available. However, as it will not be logical to assume an instantaneous diffusion of this technology, this maximum level of productivity is distinguished from the effective capital productivity, representing an average productivity used in the energy sector (*RenEngPerCap_Eff*). Diffusion of the newest technology is modeled with a first-order information delay, as seen in Figure 6.34.

For North, improvement in the energy productivity of capital is driven by the level of R&D spending on renewable energy (*RenEng_TechImp_Mult_RD*) and marginal cost of progress in the technology (*RenEng_TechImp_Mult_MC*). R&D spending on renewables is affected by the total R&D spending and the perceived non-renewable energy scarcity risk, which increases the fraction of total R&D spending made on renewable energy. On the other hand, as the level of energy productivity increases, marginal cost of improvement is expected to increase.

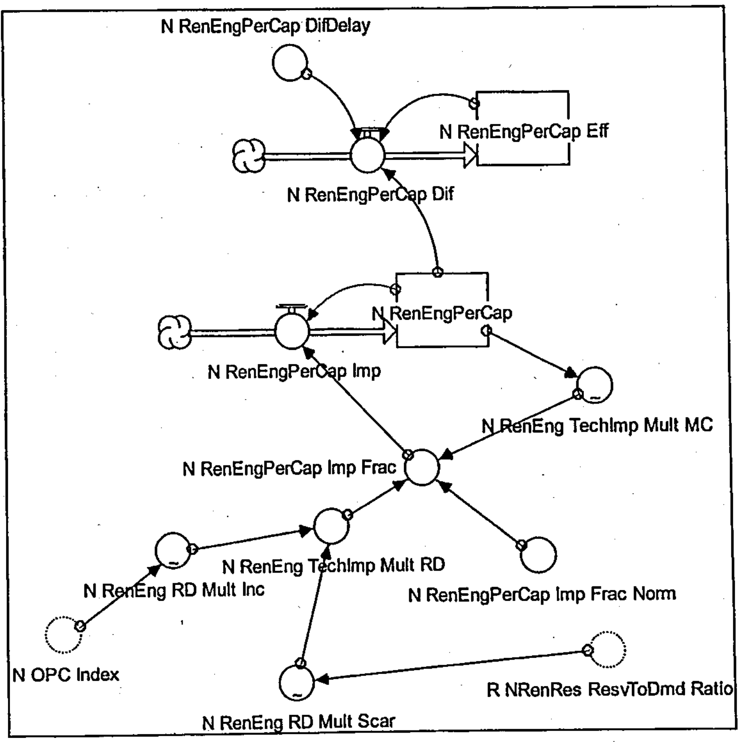


Figure 6.34. The structure related to renewable energy productivity in North

For the South block, technology is assumed to be adopted from the North block after a delay. So, a delay structure similar to the one used for technology diffusion in North is constructed for South. The rate of technology adoption (*RenEngPerCap_Dif*) is dependent on the current technology levels in South (*S_RenEngPerCap_Eff*) and North (*N_RenEngPerCap_Eff*) blocks. Related structure is given in Figure 6.35.

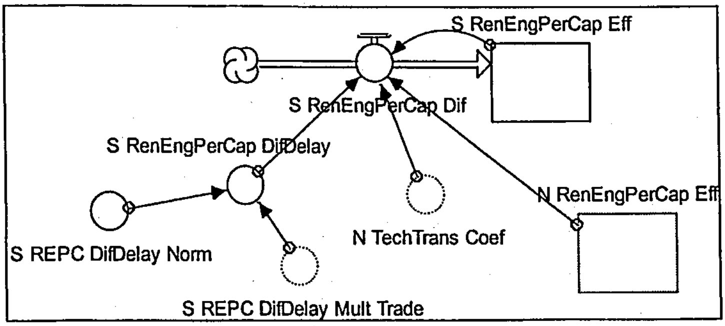


Figure 6.35. The structure related to renewable energy productivity in South

6.2.3.5. The Structure Related to Non-Renewable Resource Extraction. In the literature there are a variety of terms used to describe energy reserves, and it seems that different institutions have different meanings for similar terms. The terms resource and reserve are used as they are defined by WEC (WEC, 1998). According to these definitions resources are defined to be "the occurrences of material in recognizable form" (WEC, 1998). Reserves represent only the portion of resources, which are already identified and used for extraction. A simplified version of the McKelvey box, which is used for resource classification, is given in Figure 6.36.

	Identified	**Undiscovered**
Economic	**Reserves**	Resources
Sub-economics	Resources	Resources

Figure 6.36. A simplified McKelvey box to categorize fossil fuel occurrences

Instead of using a single stock variable to represent an aggregation of resources and reserves, the global non-renewable resource stocks are represented by two stock variables in the model. In order to prevent any confusion with the *resource* term, this type of fossil fuel stocks are named as *undiscovered reserves*, whereas *reserves* term is used as it is defied by WEC; already discovered and productive fossil fuel occurrences. The initial values for resources and reserves are set to be 600×10^6 ktoe and 170×10^6 ktoe for the year 1975, respectively. These values are estimated using the historical demand-reserve ratios and estimates regarding the undiscovered reserves (UNDP *et al.*, 2000).

Using a two-stock structure enabled modeling the discovery rate of new reserves and the extraction rate from existing reserves, separately, as seen in Figure 6.37. In this structure, each year a certain fraction of the existing undiscovered reserves are assumed to be discovered and identified as new reserves. The normal rate of discovery is defined to be affected by two factors; changing reserve-demand ratio and availability of reserves unidentified.

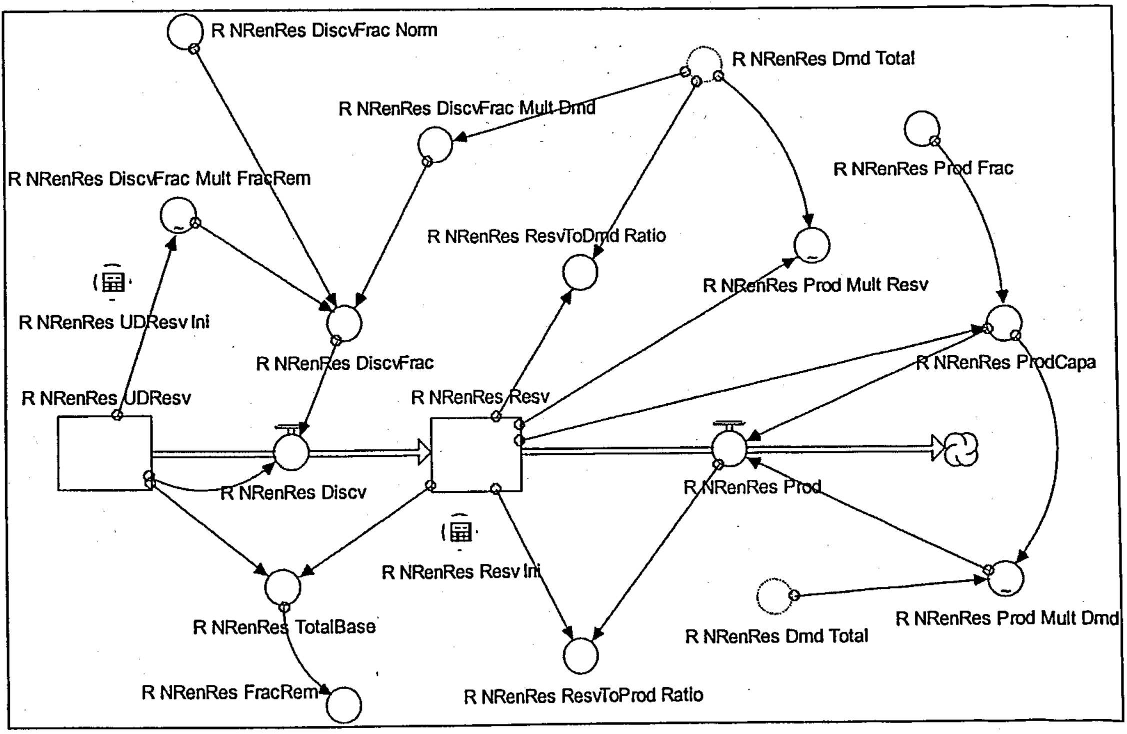


Figure 6.37. Stock-flow diagram related to non-renewable resource production

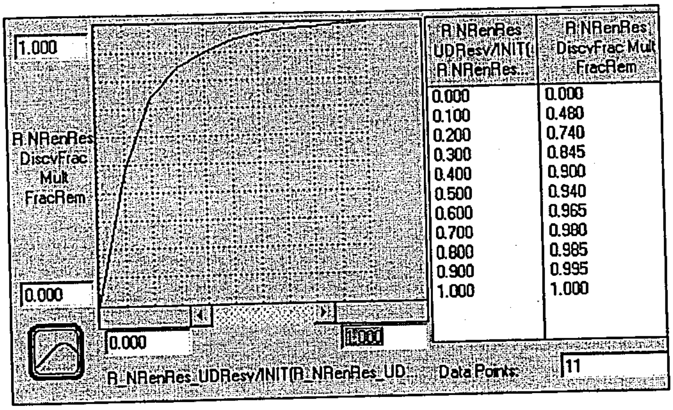
It is assumed that decreasing reserve-demand ratio (*NRenRes_ResvToDmd_Ratio*) will induce an increase in the reserve exploration activities, as it resembles decreasing capacity of currently identified reserves. This in-turn results in an increase in the exploration rate of new reserves (*NRenRes_Discv*). On the other hand, it is obvious that the rate of reserve discoveries will decrease significantly as the amount of undiscovered reserves (*NRenRes_UDResv*) vanishes in time.

$$\mathit{NRenResv\_Discv} = \mathit{NRenRes\_UDResv} \times \mathit{NRenRes\_DiscvFrac} \tag{6.9}$$

$$\begin{aligned} &\mathit{NRenRes\_DiscvFrac} = \mathit{NRenRes\_DiscvFrac\_Norm} \\ &\times \mathit{NRenRes\_DiscvFrac\_Mult\_FracRem} \times \mathit{NRenRes\_DiscvFrac\_Mult\_Resv} \end{aligned} \tag{6.10}$$

$$\mathit{NRenRes\_DiscvFrac\_Mult\_FracRem} = f(\mathit{NRenRes\_UDResv}) \tag{6.11}$$

$$\mathit{NRenRes\_DiscvFrac\_Mult\_Resv} = g(\mathit{NRenRes\_ResvToDmd}) \tag{6.12}$$

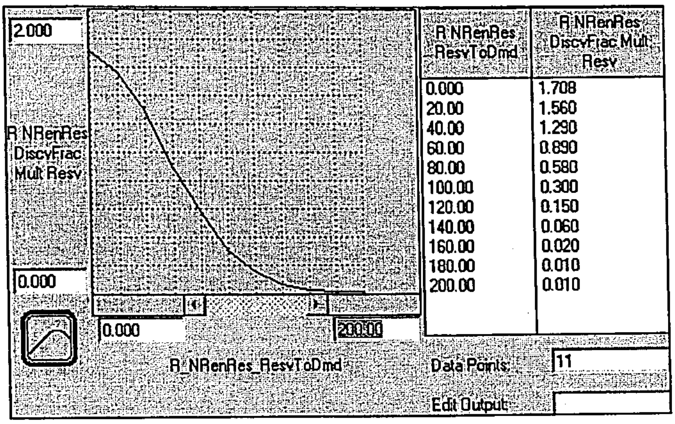


R NRenRes UDResv/INIT(R NRenRes...	R NRenRes DiscvFrac Mult FracRem
0.000	0.000
0.100	0.480
0.200	0.740
0.300	0.845
0.400	0.900
0.500	0.940
0.600	0.965
0.700	0.980
0.800	0.985
0.900	0.995
1.000	1.000

Data Points: 11

Figure 6.38. Effect of decreasing undiscovered reserves on discovery rate

The effect of remaining undiscovered reserves ($f(\mathit{NRenRes\_UDResv})$) and reserve-demand ratio ($g(\mathit{NRenRes\_ResvToDmd})$) on the discovery rate are defined as non-linear functions. The first of these functions uses the ratio of current undiscovered reserves to its initial value in 1975 and is given in Figure 6.37. Second one uses the reserve- demand ratio and is presented in Figure 6.39.



R NRenRes ResvToDmd	R NRenRes DiscyFrac Mult Resv
0.000	1.708
20.00	1.560
40.00	1.290
60.00	0.890
80.00	0.580
100.00	0.300
120.00	0.150
140.00	0.060
160.00	0.020
180.00	0.010
200.00	0.010

Data Points: 11

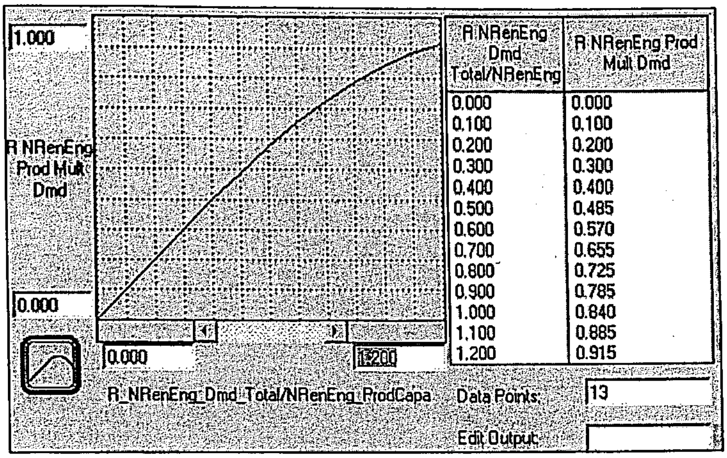
Edit Output:

Figure 6.39. Effect of decreasing reserve-demand ratio on discovery rate

The second flow in this structure is the extraction from known reserves, or non-renewable resource production (*NRenRes_Prod*). This flow is also defined to be dependent on the demand for the resources (*NRenRes_Dmd_Total*) and the maximum amount that can be extracted in a year (*NRenRes_ProdCapa*). In defining the maximum amount of resource that can be produced, a delay of 10 years is used for extracting the total of currently known reserves. In constraining the amount of resource production with the available capacity, a fuzzy-min structure is used in order to avoid unrealistic discontinuities in the production figures. According to this formulation, production is determined as follows;

$$NRenRes\_Prod = (NRenRes\_ProdCapa) \times (NRenRes\_Prod\_Mult\_Dmd) \qquad (6.13)$$

The multiplier from demand (*NRenRes_Prod_Mult_Dmd*) is a graphical function which enables a soft transition in the production behavior, when demand exceeds capacity. The function used for this purpose can be seen in Figure 6.40.



R NRenEng Dmd Total/NRenEng	R NRenEng Prod Mult Dmd
0.000	0.000
0.100	0.100
0.200	0.200
0.300	0.300
0.400	0.400
0.500	0.485
0.600	0.570
0.700	0.655
0.800	0.725
0.900	0.785
1.000	0.840
1.100	0.885
1.200	0.915

Data Points: 13

Figure 6.40. Fuzzy-min function used for renewable resources production

The resources produced are allocated to three blocks according to their demands. In cases of production shortage, where production fails to satisfy all incoming demand, resources are distributed among blocks according to their fractional share in the total resource demand (*NRenRes_Dmd_Nfrac* and *NRenRes_Dmd_Sfrac*). The structure responsible for the allocation of produced resources among blocks is presented in Figure 6.41.

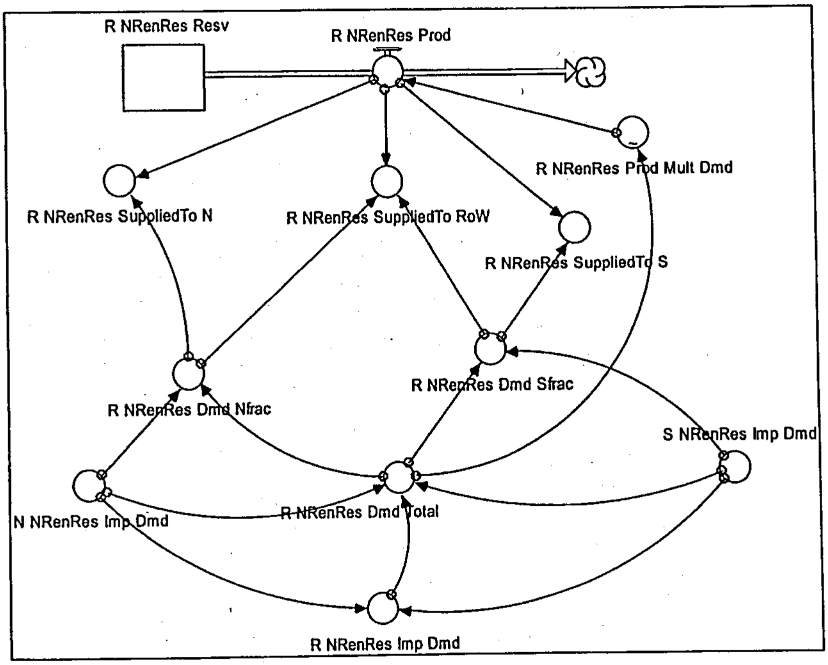


Figure 6.41. The structure for allocation of the produced non-renewable resources

6.2.4. Dynamics of the Energy Sectors in Isolation

The behavior observed in the isolated run of the energy sector of RoW, which is responsible for global non-renewable resource production, with constant global resource demand is presented in Figure 6.42 and Figure 6.43.

Behaviors observed for undiscovered resource reserves and its outflow are presented in Figure 6.42. Undiscovered reserves level declines throughout the run as a consequence of the outflow from this stock to discovered reserves stock, which represents new reserve discoveries. As amount of undiscovered reserves decline, probability of finding new reserves also decreases and this results in a gradually decreasing discovery rate. Due to this relation between the undiscovered reserves and its outflow, undiscovered reserves decrease with a diminishing rate of change throughout the run.

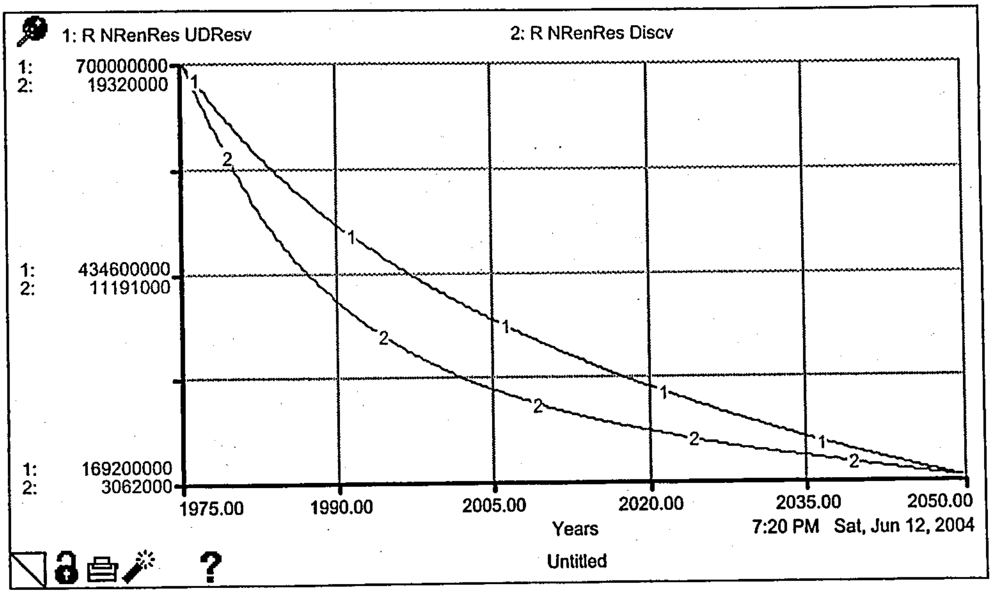


Figure 6.42. Undiscovered resource reserves and resource discovery outflow in isolated sector run with constant demand

An inverted-U shaped behavior is observed for non-renewable energy resources reserves (see Figure 6.43). In the growth phase, amount of new reserves added as a result of new discoveries exceed the constant resource production. However, as mentioned above discovery rate decreases over time due to decreasing undiscovered reserves. At some point in the run, the discovery rate falls below the production rate that is constant for this run, and this represents the beginning of the declining phase of the reserves.

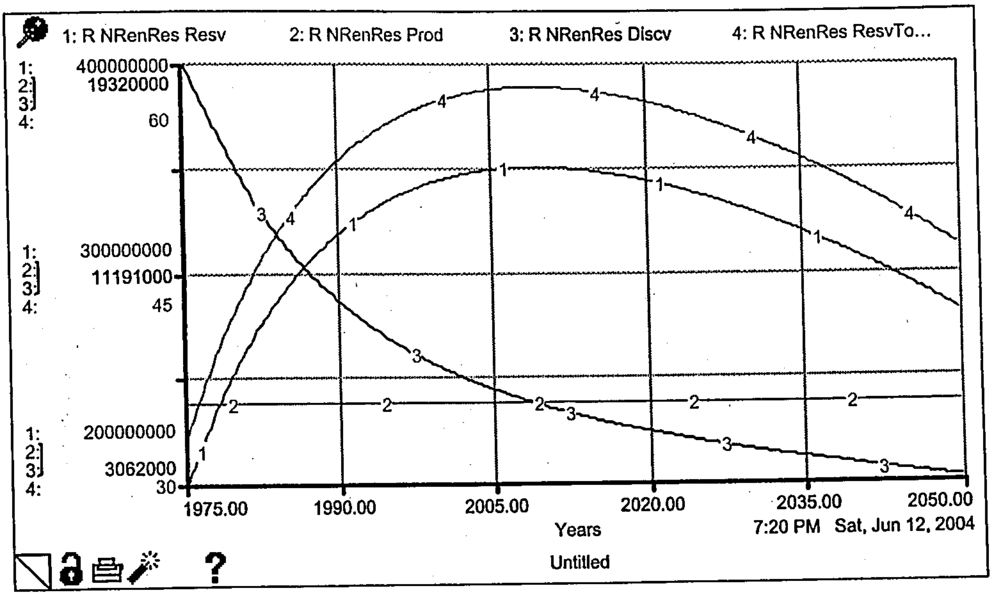


Figure 6.43. Discovered resource reserves and related flows in isolated sector run with constant demand

The behavior of this sector with exponentially increasing resource demand is presented in Figure 6.44 and Figure 6.45. Overall behavior for the undiscovered reserves and its outflow is almost the same with the constant demand case. Undiscovered reserves decrease with a decreasing rate of change. As in the constant demand case, known reserves increase until the time increasing demand exceeds decreasing discovery rate. After that point on reserves start to decrease gradually and dependent on that yearly production capacity also decreases. This generates the inverted-U shaped production curve; first phase determined by the increasing demand and second phase dominated by the declining production capacity (see Figure 6.45).

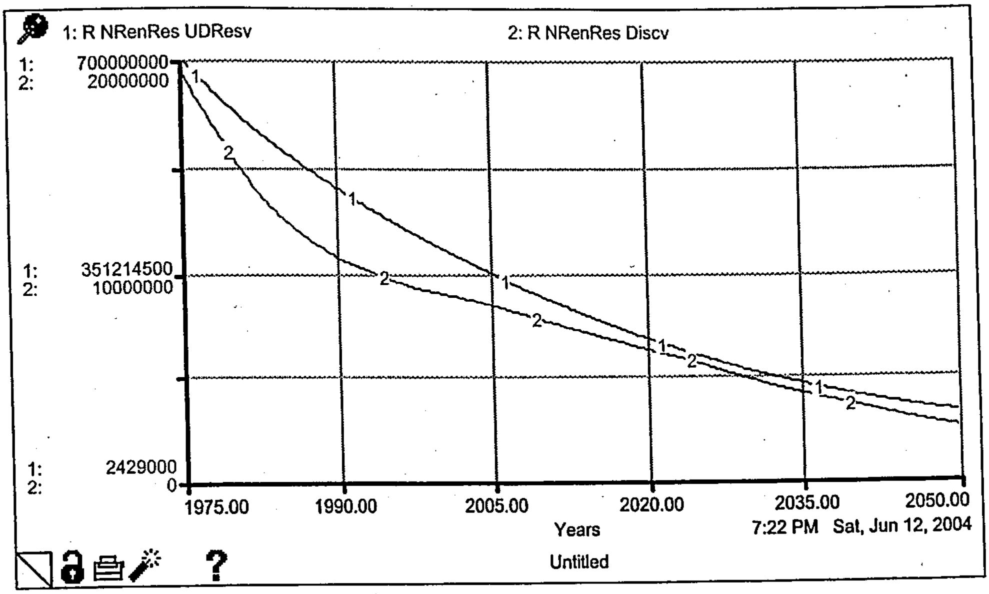


Figure 6.44. Undiscovered resource reserves and resource discovery outflow in isolated sector run with increasing demand

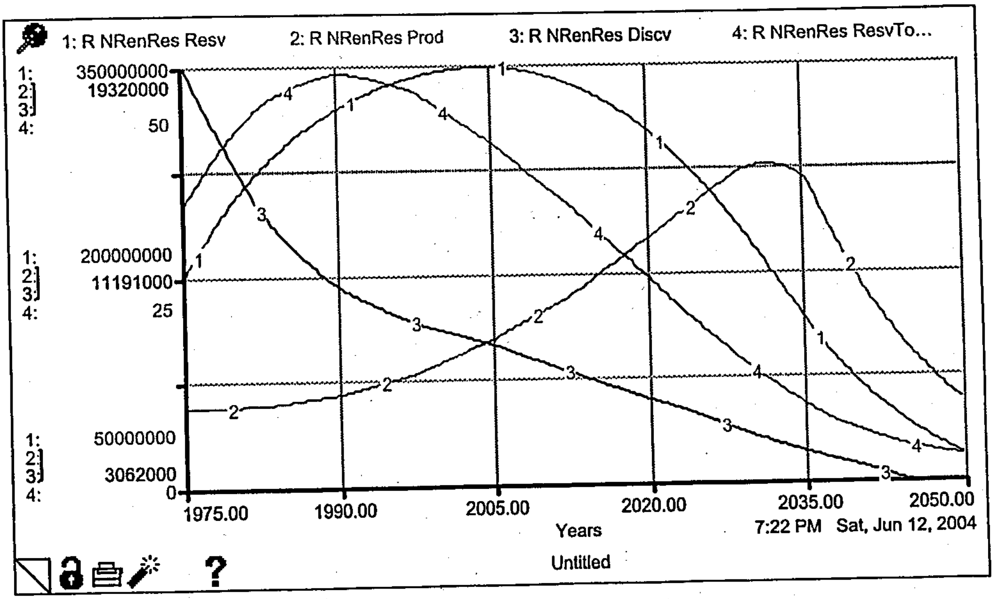


Figure 6.45. Discovered resource reserves and related flows in isolated sector run with increasing demand

Outputs from the isolated runs of energy sectors (energy sectors belonging to North and South) related to allocation of energy demand are presented with Figure 6.47 and Figure 6.46. In the first case, a constant reserve-demand ratio, which indicates constant availability of non-renewable resources, is employed. As a result, it is observed that there is no tendency to increase the share of renewable energy in total energy demand. The target level of renewable energy share stays constant and renewable energy capacity overshoots and then converges from above to this target in the run (see Figure 6.46).

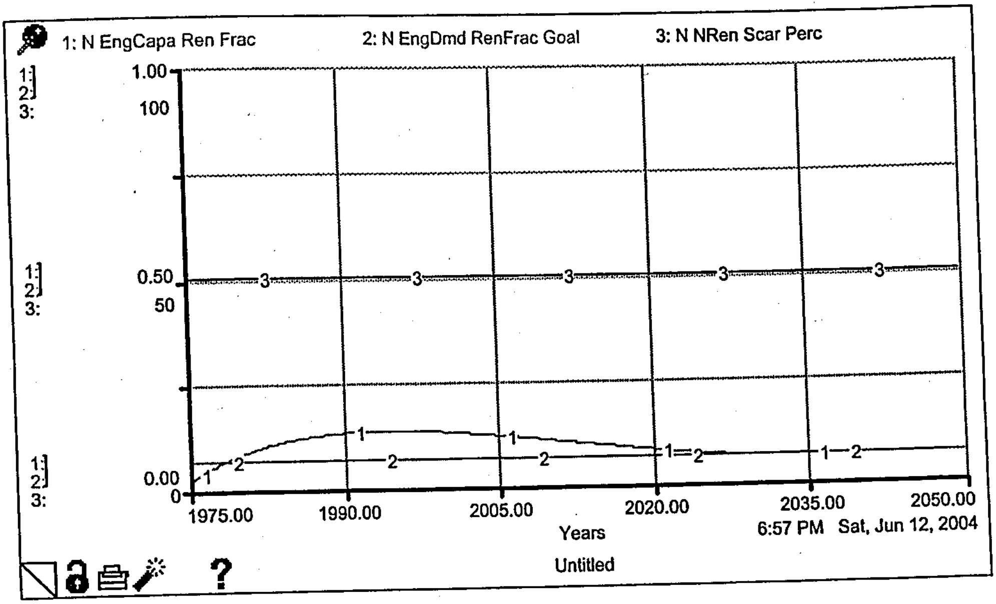


Figure 6.46. Target and actual level of renewable energy capacity in isolated sector run with constant resource availability indicator

This situation is also visible in Figure 6.47, which demonstrates the changes in demands for renewable and non-renewable energy as total energy demand increases. Non-renewable energy clearly dominates the energy demand, and this dominance prevails throughout the run.

In order to demonstrate sector's behavior, a decreasing reserve-demand ratio, which indicates decreasing non-renewable resource availability, is used for the second isolated run. As seen in Figure 6.48, as perceived level of reserve-demand ratio (Line 3 in Figure 6.48) decreases, target level for the share of renewable energy in total energy demand increases. Renewable energy generation capacity follows this target with a certain delay.

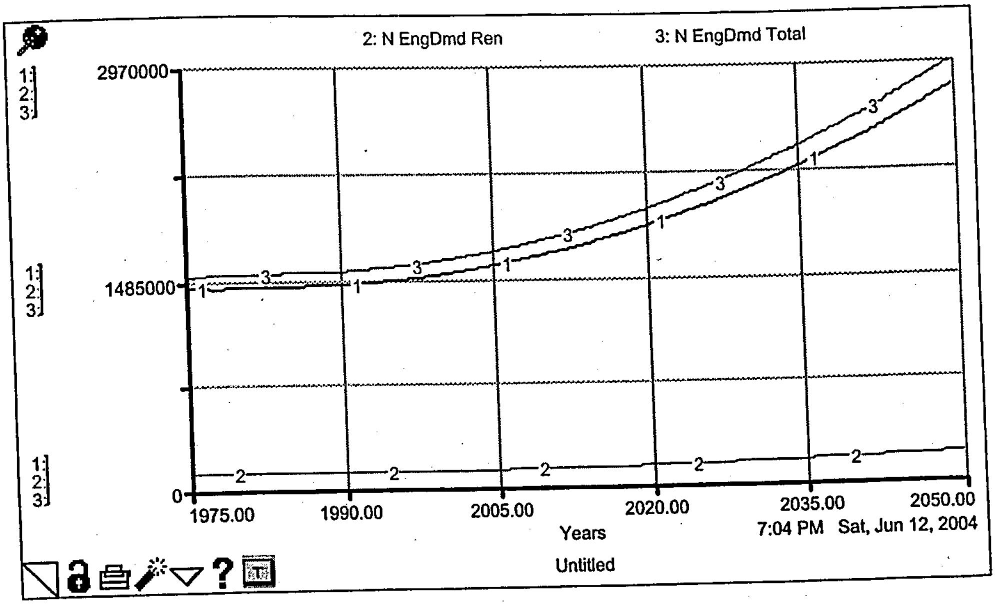


Figure 6.47. Energy demand allocation in isolated sector run with constant resource availability indicator

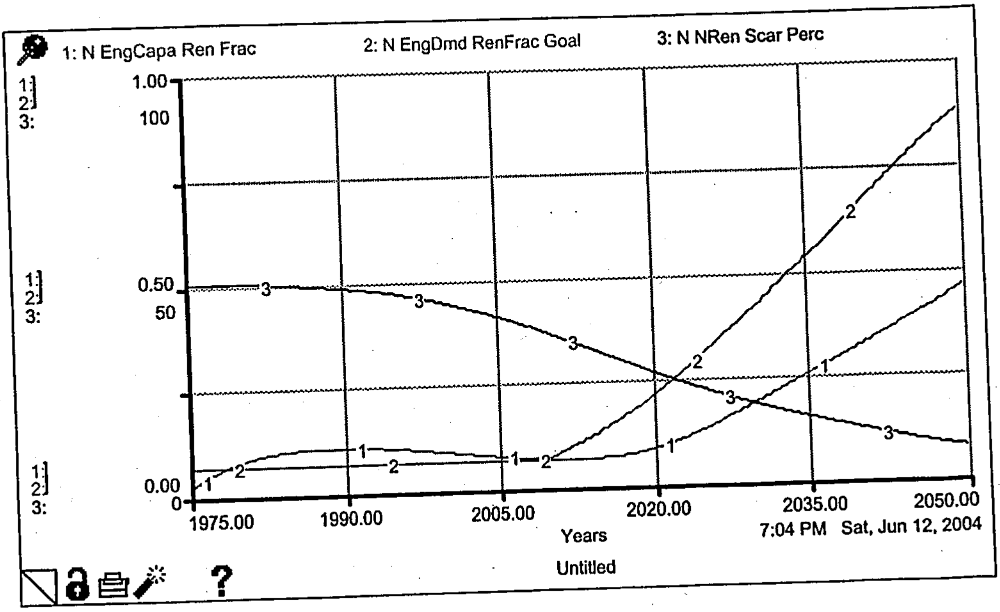


Figure 6.48. Target and actual level of renewable energy capacity with decreasing resource availability indicator

The effect of perception regarding decreasing non-renewable energy resources is evident in Figure 6.49. As perceived scarcity indicator decreases, demand for non-renewable energy shifts to renewable energy. Consequently, a significant demand increase for renewable energy coupled with a gradual decrease in non-renewable energy is observed.

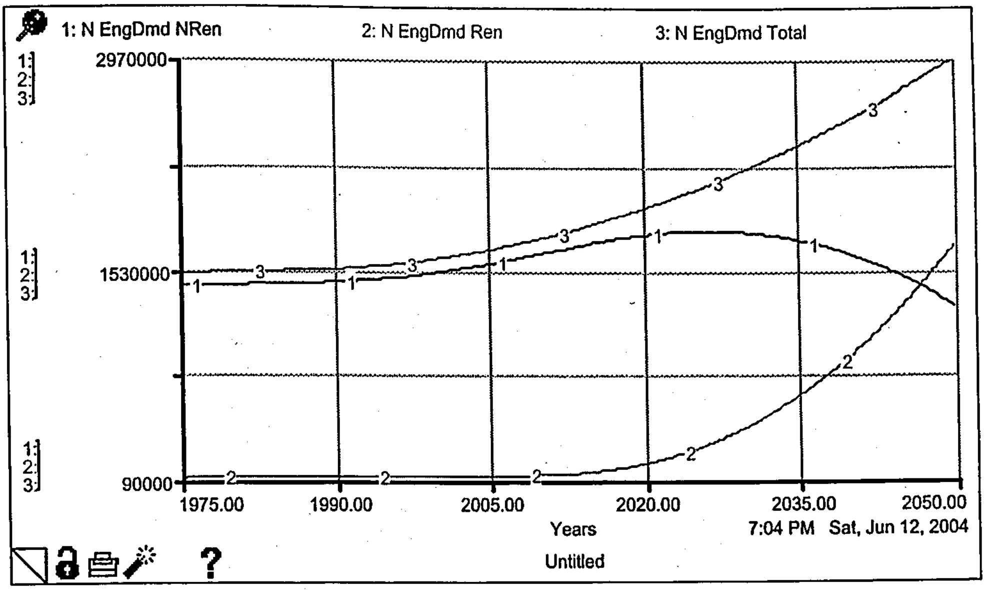


Figure 6.49. Energy demand allocation in isolated sector run with decreasing resource availability indicator

6.3. Economic Activity Sector Group

6.3.1. Background Information

20th century can be characterized as an era of exponentially growing global economic activity, which even surpassed the extensive growth in the global population. The global GDP has grown from about 2 trillion to nearly 30 trillion dollars (in constant 1990 dollars) during last century, with an annual growth rate of 2.7 per cent. In per capita terms, global GDP has grown from a bit over 1000 to about 5000 dollars. According to the statistics provided in *"World Development Indicators 2003"* report (World Bank, 2003), global economic output quadrupled since 1960. During the same period global population only doubled (see Figure 6.50), and GDP per capita increased to an average of 5.6 thousand dollars in 2000 from its 1960 level of 2.6 thousand dollars, on a global scale (World Bank, 2003).

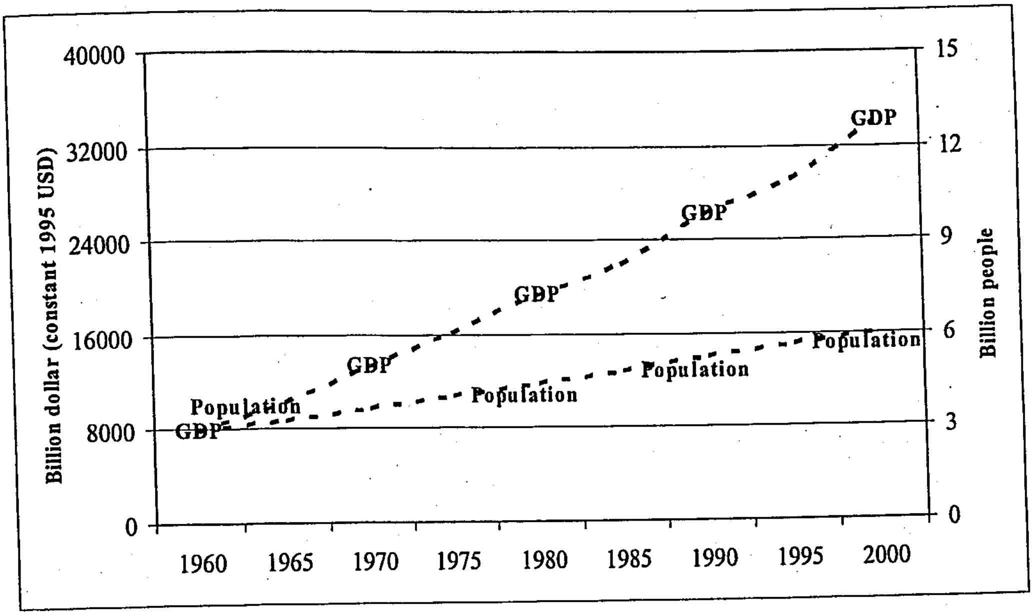


Figure 6.50. Global GDP and population between 1960 and 2000

However, it will be a deception to assume that such an increase in per capita output is experienced homogeneously all over the world. When different sets of countries with differing development/industrialization status are studied, it is evident that growth in per capita income demonstrates a significant variability.

According to the *State of the World 2002* report (WWI, 2002) assets of just three individuals matched the combined national economies of the poorest 48 countries in 1997. A more striking indicator of inequality comes from the *Human Development Report* of UNDP (1994), which indicates that the per capita income gap between the richest 20 per cent of the world's population and the poorest 20 per cent increased from 30-1 to 60-1 just between 1960 and 1991. Such a statement clearly supports the idea that the economic change of the 20th century is extremely uneven and that income inequalities among countries increased significantly. A similar comparison is performed between the North and South blocks determined for this study. Using the GDP per capita figures (PPP) for the last 25 years, a widening gap between per capita income levels is observed. However, the North-South GDP per capita ratio (GDP per capita in North divided by GDP per capita in South) is observed to have a negative slope in this comparison (see Figure 6.51).

Despite the consensus on the significance of such a gap, two opposite schools of ideas exist regarding the future pattern of it. One of them proposes that the gap will continue to get wider due to the inequalities in the current global economic and trade systems. On the other hand, another group supports the idea that today's developing economies will experience a serious economic growth and catch-up the developed economies by benefiting from the global free trade and technology innovated by developed nations.

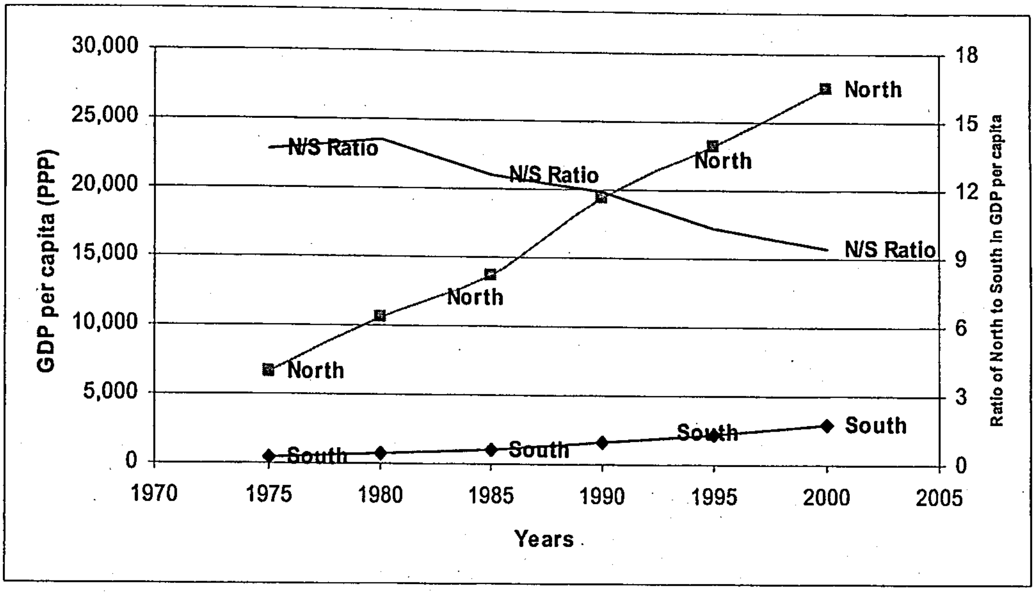


Figure 6.51. GDP per capita in North and South between 1975 and 200

The future economic development that will be experienced in South will play a vital role in determining the changes in this welfare gap between the blocks. Considering the different circumstances, a development pattern similar to the one North experienced in the past seems to be a low probability option for South. Development era of North was a period of plenty resources and markets with weak competition. However, today South is far away from those advantages, as it faces a harsh competition in global trade, a damaged environment and almost depleted resources (Myrdal, 1957; Angelopoulos, 1972). Contrary to these, crowded labor force of South and the possibility of technology adoption from North are two major opportunities that can boost development.

Current demographic structure provides a crowded labor force, and this labor force is also expected to expand at least during the following 50 years. Considering the expected shrinkage in the labor force of North, this makes South a significantly labor abundant economy compared to North, which may be an advantage for South in the labor-intensive sectors. Additionally, based on these trends in labor force, it may be concluded that output-capital ratio of South will be less affected by the capital deepening effect. Capital deepening can be considered as an increase in capital relative to other production factors, especially labor. Assuming that no changes occur in the capital embedded technology, output rate per capital must decline (Spencer and Amos, 1993; Mankiw, 1999).

The second important point regarding South's development is technology, which is a very important factor in overall productivity. Continuous improvements experienced in technology constitute a significant opportunity for South seeking a fast growth, but South seems to be far away from generating new technology. It mainly acts as a technology adaptor, benefiting from the previous technological accomplishments of North. Regarding this status of South, Ocampo states that *"...in developing countries innovations are primarily associated with the spread of new technologies previously developed in the industrial centers. Thus, these innovations represent the moving targets which generate the windows of opportunity for developing countries"* (Ocampo, 2004; pp. 15). It is clear that availability of advanced technologies is a great chance for South, but the degree of its impact on development will be dependent on South's ability to adopt and use those technologies, as well as North's willingness to share that technology.

Although the two issues mentioned above provide valuable opportunities, there are also though challenges in the course of development for South. Development model of the North can be characterized as material-intensive, driven by fossil fuels, based on mass consumption and mass disposal (WWI, 2002). However, a significant portion of the fossil fuel reserves are currently being depleted by North, and the North-originated mass disposal damaged global commons (oceans, atmosphere, etc.) severely. Under these circumstances South seems to be restricted in fossil fuel usage and disposal, which may have a strong negative impact on the development of South.

6.3.2. Fundamental Approach and Assumptions

This economic sector group is mainly built to generate indicators for the volume of global economic activity. Such indicators are required both to monitor the economic system and to estimate the environmental impacts of economic activity. On the other hand, social well-being and development level of countries are directly correlated to per capita economic output.

For measuring the intensity of the economic activity, gross domestic product (GDP) is selected as the key indicator. However, as GDP is the sum of market values of all economic output, it is not an objective indicator of the physical content of the output generated. Identical outputs can generate differing GDP figures in two countries due to exchange rate and price differences. As market clearing agents like price and exchange rate are not explicitly modeled in this study, an indicator of economic activity purified from exchange rate and price differences between countries is required. In this manner, GDP converted to international dollars using purchasing power parity data is used as the indicator of the economic activity. By definition, an international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States.

On the other hand, GDP per capita is selected as the indicator for wealth and economic development level of a nation. The term economic development in this context refers to the process of transition experienced in economic production patterns coupling the increased per capita output generated. Most typical characteristic of this process is the shift in the dominant sector of the economy. Dominance of agriculture shifts to manufacturing sector as an economy develops. In the course of development, finally service sector becomes the dominant one in the economic output. In *WORLD-3* study of Meadows *et al.* (1974), it is argued that GDP per capita is a poor indicator for wealth and development. As a supporting fact, they propose natural resource rich countries, which have considerably high GDP per capita figures and poor manufacturing and service sectors. Also their social dynamics are closer to underdeveloped nations than nations with almost equal per capita income figures (Meadows *et al.*, 1974). This statement is completely valid in the context of

WORLD-3. However, in our study countries that do not fit the traditional economic development path, like natural resource exporting ones, are excluded both from North and South blocks. Hence, the handicap of GDP per capita figure mentioned in *WORLD-3* study is almost eliminated.

Constructing the mainframe of the economic system, fundamental approaches used in *WORLD-2* (Forrester, 1971) and *WORLD-3* (Meadows *et al.*, 1974) models regarding economic activity are used as guidelines. In both of these models, economic activity is modeled as a supply-oriented system, in which generated output is assumed to be either consumed, or invested. No market mechanisms are introduced, considering the aggregation level and the time horizon of the models, which is long enough to ignore short-term market fluctuations and to assume that global supply-demand are in equilibrium. Also economic flows and accumulations are represented with physical amounts avoiding the pricing and valuation mechanisms.

Those assumptions mentioned above also constitute the fundamentals of the model used in this study. No market adjustment mechanism as price, wage, interest or exchange rate is modeled explicitly. Once more, it is worth restating that main concern of the study is to obtain an understanding for the volume of the economic output. The effect of these short-term market adjustment mechanisms is assumed to be insignificant in determining the long-term dynamics of economic output, and such an assumption is also supported by Saeed (1994). Hence, global demand for output is assumed to be equal to the global supply in the 75-year time horizon of the model.

Economic activity is assumed to be supply-driven, which indicates that amount of global consumption and investment is determined by the output supplied by the economic system. Treating the economic output as a physical entity, it is logical to assume that this output will eventually be either consumed or used to generate further output in the long-run. As there is no market structure in the model, there is no need to model supply and demand separately. Assuming the equivalence of demand and supply, it is satisfactory to model one of them, and in this study supply side is chosen.

Economic system is designed as a growth-oriented one, in which there is no output level used as a goal to reach. Ultimate motivation of the system is assumed to achieve further growth. This assumption can easily be supported by exponential growth trends observed in the global economic activity, and employment of annual growth rates as one of the most important indicators of achievement in real life. Hence, a certain fraction of output generated is assumed to be allocated for investment independent of the size of the economy or the level of output generated.

As mentioned before, *WORLD-2* and *WORLD-3* form the basis of the approach and assumptions mentioned up to now. However, model structures used in *WORLD-2* and *WORLD-3* do not match the purposes of this study quite well in some of the sectors. Hence, model for economic activity is tailored for the purpose of this research.

The nature of the problem studied in this research requires an economic structure which can provide probable diversification paths for North and South blocks. Four major issues, which may play important roles in a probable economic diversification, are identified in this study. These issues are production specialization, labor skill development, capital technology development, and changes in output-capital ratio.

In order to capture the production diversification between blocks, a two-segment economic system, which generates two different types of goods, is used. Instead of using the traditional 3-segment economy with agriculture, manufacturing and service segments, we preferred to divide the output according to the technology required to generate them. As a result, we come up with two segments, or two output types classified with respect to their technology content; high technology goods and low technology goods. It is assumed that outputs related to agriculture, forestry, fishing, mining and labor-intensive manufacturing belong to the low technology category. On the other hand, some typical fields whose outputs can be included in high technology category are banking, insurance and capital-intensive manufacturing. Such an approach is mainly inspired by the research of Cole and Chichilnisky (Chichilnisky and Cole, 1979; Chichilnisky *et al.*, 1979) regarding technological differences and their impacts on North-South relations. Model is designed to provide country blocks the flexibility of shifting production capacity between these two goods. In the model, decisions regarding the allocation of production capital a are mainly affected by the marginal gains or losses of the blocks in shifting a unit capital between the production of these two good types.

As mentioned above, it is assumed that the global equilibrium exists between the gross global output and demand. However, this is not necessarily true within sectors; global demand for low technology goods may be more than its global output. This is a natural consequence of two agents that have changing preferences in consumption and investment, primarily due to experienced development. Hence, a simple supply-demand mechanism is introduced within each sector, which seeks the global equilibrium for individual sectors. It is worthwhile to note that this is not an explicit market mechanism. We assume that market will react to such an imbalance and global equilibrium will be restored, but the mechanisms of this reaction are not included in the model.

In *WORLD-3* model, output-capital ratio is assumed to be constant. This assumption was based on another assumption that technological progress and capital deepening are two opposite effects on output-capital ratio with almost equal magnitudes on the global scale. However, in the scope of this study both capital deepening and technological progress experienced by different blocks may vary significantly. Hence, output-capital ratio is modeled as a variable dependent on capital technology, labor skill and capital-labor ratio, which are also variables endogenously simulated in the model.

As a simplification, it is assumed that output from each sector is homogenous and output is not differentiated according to its source. Hence, no difference is assumed to exist between low technology goods produced in North and South. Also, it is assumed that market for these goods are totally global, and transportation costs and delays are negligible. Such a design was one of the market structures used in global models, as it is depicted by Bremer (1987). This set of assumptions results in a system, in which both block are equally likely to supply goods to any demand point and this constitutes the fundamental approach used in determining the amount of output exchanged between blocks. The details of the mechanism used are given in the following section.

During the course of preliminary research, international long-term debt is recognized as an important issue that may have serious impact on the development dynamics of South. However, aggregation level used in the study is inappropriate to represent endogenous dynamics of international debt properly. Hence, not the actual debt mechanism, but the expected effects of a serious debt crisis are introduced to the model in certain scenario runs. In these scenarios, it is assumed that poor debt status of South would result in an imbalance in the amount of goods exchanged in favor of North. This assumption is based on the expectation that the market mechanisms will increase exports and decrease imports via several means in a poor debt servicing status.

6.3.3. Description of the Structure

The sector group related to economic activity is composed of four sectors. As in the energy resources sector group, two of them are structurally almost identical and represent the economic activity of North and South. Third sector belongs to Rest-of-the-World (RoW) block, and is a simplified calculation sector responsible for generating estimates for the gross economic output level of RoW. Final sector is a calculation sector used for calculating the amount and types of goods exchanged between blocks, which may be called *global market sector*.

Sectors in this sector group mainly interact with related energy and population sectors. Output capacity of the economy sector determines the energy demand to be satisfied by the energy resources sector. Meanwhile, utilization of this capacity is constrained by the energy supply capacity of the energy resources sector.

Most important feedback-loop of the economic system is the reinforcing loop including capital, investment and output. Increasing output means more investment, and increasing capital with investment produces more output. This loop is the driving motor of the economic growth experienced in both of the blocks.

Additionally, output generated in this sector determines the per capita income, which is the main indicator for wealth and economic development. This variable has a delayed effect on health expenditures made and the desired number of children; the two very important variables affecting the population dynamics. Changes in the population affect the economic performance via changes in labor availability.

A basic causal-loop representation of these major relations of economic system with demographic and environment systems is presented in Figure 6.52.

A main production factor in the determination of output is identified to be capital. The term capital represents every physical factor used in economic output generation process, excluding labor and resources. Some typical examples for the content of the capital stock used in this model are machinery, vehicles, buildings and infrastructure. Due to obvious data problems regarding initial value of this physical capital stock, estimates are generated using the two datasets available from World Bank (King and Levine, 1994; Nehru and Dhareshwar, 1993) and the estimation approach used in *GLOBUS* study (Bremer, 1987). In this estimation procedure, an initial capital stock value is estimated using more reliable and available statistics like gross capital formation and capital growth figures. Equation (6.14) from *GLOBUS* study was used in this estimation.

$$\mathrm{Capital} = \frac{\mathrm{GrossCapitalFormation}}{\mathrm{CapitalGrowthFraction} + \mathrm{CapitalDepreciationFraction}} \qquad (6.14)$$

This estimation procedure provides an approximate initial physical capital stock value of 14 trillion international dollars for North and 4 trillion international dollars for South block.

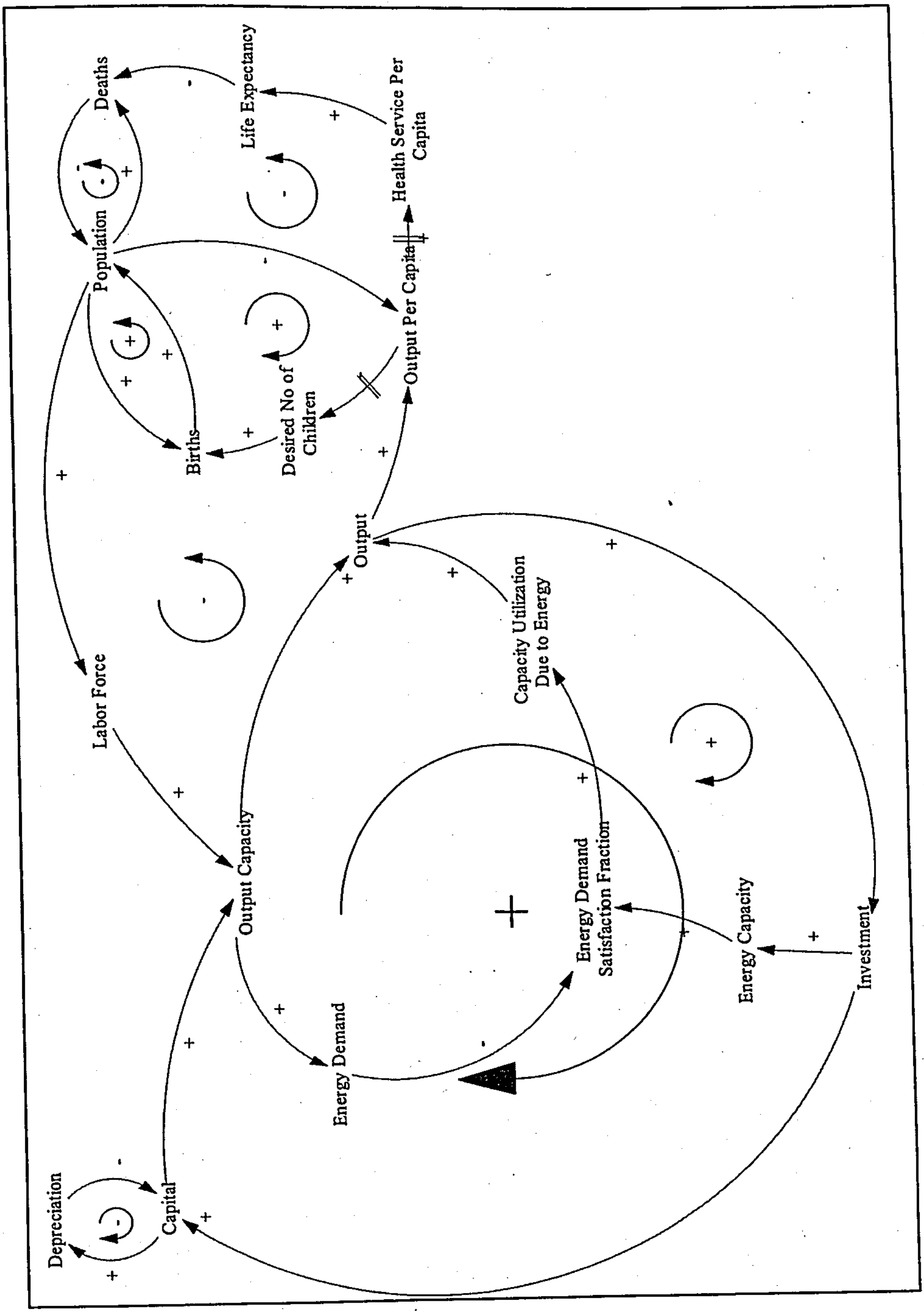


Figure 6.52. Basic interactions of economic, demographic and environment systems

The capital stock in the model is manipulated through an investment and a depreciation flow. The average lifetime of capital is approximated to be 25 years and equal for both blocks. According to our formulation, 0.04 (1/25) times the capital stock is lost yearly due to depreciation. On the other hand, new capital is added in the form of new investment (see Figure 6.53).

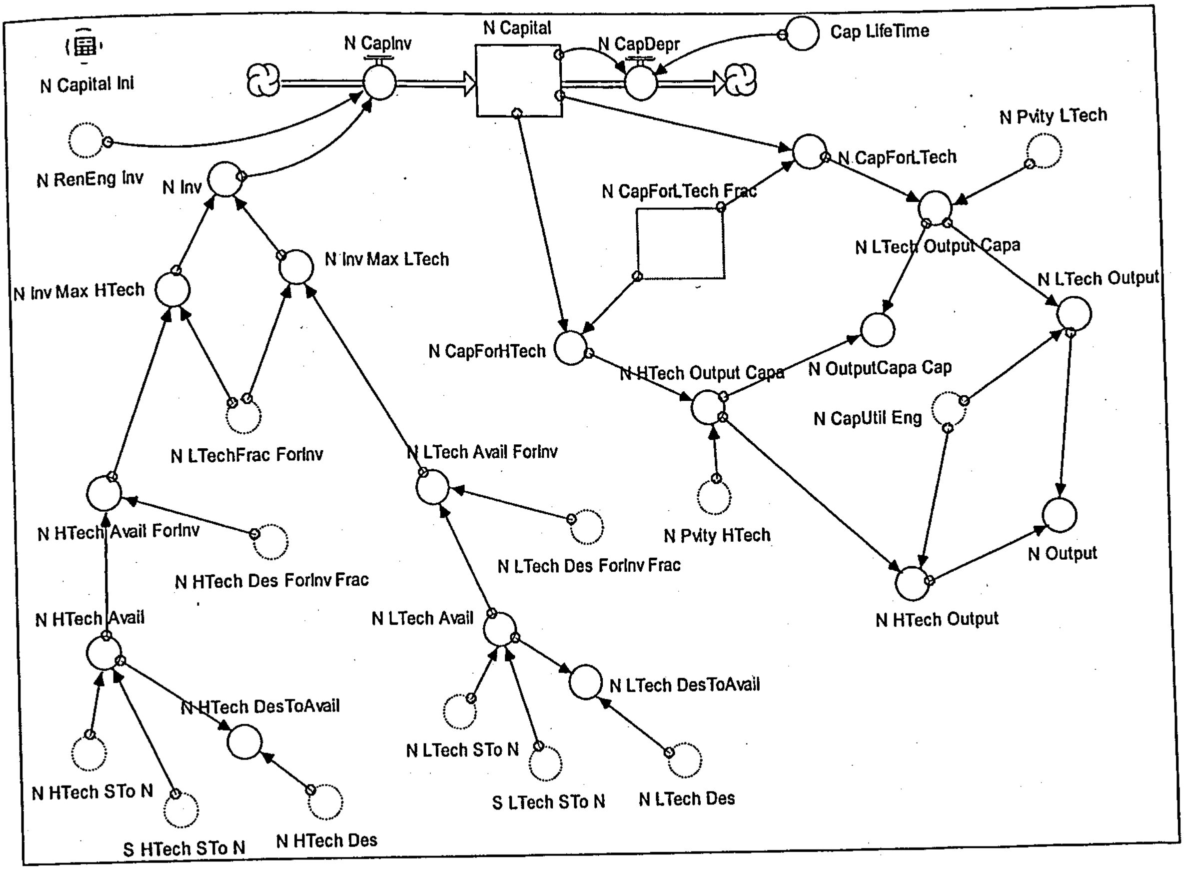


Figure 6.53. Stock-flow diagram related to generation of gross output, investment and depreciation

Capital dedicated to individual segments are calculated by using the aggregated capital stock value and the variable representing the fraction of capital dedicated to each segment (*CapForLTech_Frac*, *CapForHTech_Frac*). Based on these capital amounts dedicated to each segment and the output-capital ratio in that segment, output capacity of the segments are determined. However, the realization of this output capacity is dependent on the energy availability. As long as there is sufficient energy capacity, output capacities of the segments are totally realized. In the contrary case, outputs from segments are constrained by the output level that current energy capacity can support. See Figure 6.53 for the related stock-flow representation.

As mentioned before, output represents the amount that will be consumed and invested. Hence, the desired consumption and investment figures are calculated using the output generated and the fraction of output allocated for investment (*Inv_Frac*). Although it is clearly dependent on several market parameters, it is assumed that in the long-run propensities of blocks to invest stay stable, so investment fraction is set to be constant and equal to 0.25 for both blocks. In other words, 25 per cent of yearly output is directly used, or exchanged for the goods to be used in capital formation. For some of the scenario simulation runs, the variable investment propensities are also used for blocks.

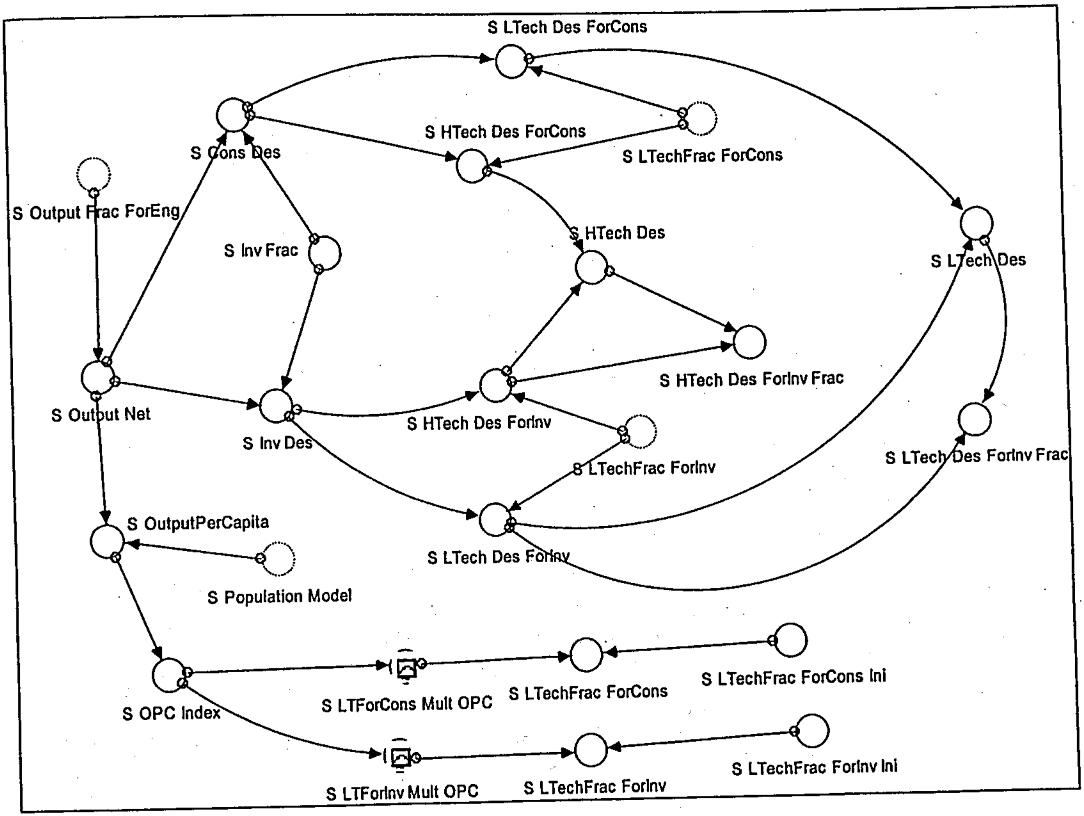


Figure 6.54. Stock-flow diagram related to determination of final demand for high and low technology goods

The consumption and the investment are assumed to be a mixture of two good types. Preferences of the blocks regarding the relative share of particular good types in these mixtures are defined as variables in the model. These preferences are assumed to be dependent on the block's economic development level. We assume that low technology goods' share in both consumption and investment decrease as the economy develops. This assumption may be supported by the change in agricultural goods' share in final output as GDP per capita changes. 152 data points are investigated, and the relationship between the economic development indicator (*GDP per capita*) and the low technology product group (*agricultural output*) is observed to be as in Figure 6.55. On the other hand, change in the service output, which may be partially accepted as a high technology output also supports our assumption.

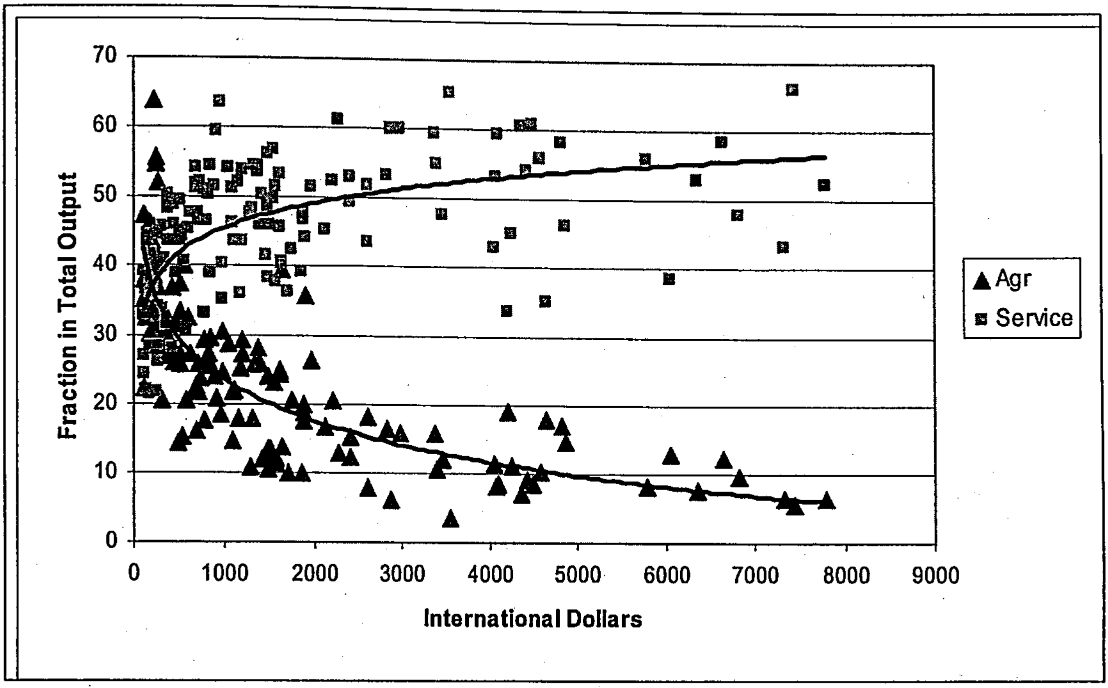


Figure 6.55. Agricultural and service outputs vs. GDP per capita

Based on the desired investment and consumption figures, and using the fractions of good types preferred for consumption and investment, final demands for good types are determined. Equations (6.15), (6.16) and (6.17) demonstrate the calculation steps used in determining the final demand for high technology goods in North. Identical equation sets are used for South block.

$$N\_HTech\_Des\_ForCons = N\_Cons\_Des \times (1 - NLTechFrac\_ForCons) \quad (6.15)$$

$$N\_HTech\_Des\_ForInv = N\_Inv\_Des \times (1 - NLTechFrac\_ForInv) \quad (6.16)$$

$$N\_HTech\_Des = N\_HTech\_Des\_ForInv + N\_HTech\_Des\_ForCons \qquad (6.17)$$

where,

N_HTech_Des: High technology goods desired, total (million dollars)
$N\_HTech\_Des\_ForInv$: High technology goods desired for investment (million dollars)
$N\_HTech\_Des\_ForCons$: High technology goods desired for consumption (million dollars)
N_Cons_Des: Desired consumption (million dollars)
N_Inv_Des: Desired investment (million dollars)

The demands set by each block for two kinds of goods are satisfied at a global market place, which is constructed as a calculation sector outside the North and South economy sectors (see Figure 6.56). According to the fully integrated global economy assumption, no preference between suppliers and consumers are set in the market. Every consumer is equally likely to get goods from each supplier, and every supplier is equally likely to send goods to each consumer. Based on these assumptions, the amount of goods shipped from a block to another is determined using the weight of the consumer in global market. This weight is calculated as the share of a block's demand for a specific good in global demand for that good. In order to clarify this assumption, consider that 80 per cent of global demand comes from North for high technology goods. This means 80 of every 100 high technology goods consumed will be consumed in North. In such a case, if there is no preference among consumers, it is realistic to assume that of 100 high technology goods sold by any supplier, 80 will be purchased by North. Goods exchanged between blocks are determined according to this approach.

As an illustration, equations used to determine the amount of high technology goods shipped from South to North are given below;

$$N\_HTech\_MrkShr = N\_HTech\_Des / G\_HTech\_Dmd \qquad (6.18)$$

$$S\_HTech\_SToN\_Frac = N\_HTech\_MrkShr \qquad (6.19)$$

$$S\_HTech\_SToN = S\_HTech\_Output \times S\_HTech\_SToN\_Frac \qquad (6.20)$$

where,

S_HTech_SToN : High tecnology goods sent to North from South (million dollars)
S_HTech_Output : Gross high technology goods output of South (million dollars)
N_HTech_MrkShr : Share of Northern demand for high-tech goods in global market (unitless)
N_HTech_Des : Demand of North for high-tech goods (million dollars)
G_HTech_Dmd : Global demand for high-tech goods (million dollars)

For any block, total high and low technology goods available for consumption and investment equals to the sum of shipments from other block and its internal shipments.

Investment level is determined according to the availability of high technology and low technology components required for the investment mixture. It is assumed that these two types of goods are not interchangeable in constituting the capital investment mixture. Hence, in each period, one of the good types set the bottleneck on the maximum level of capital investment that can be realized (Refer to Equations (6.21)-(6.24) for related calculations). The stock-flow representation related to the investment can be seen in Figure 6.53.

$$S\_InvMax\_LTech = S\_LTech\_Avail\_ForInv/S\_LTechFrac\_ForInv \qquad (6.21)$$

$$S\_InvMax\_HTech = S\_HTech\_Avail\_ForInv/S\_HTechFrac\_ForInv \qquad (6.22)$$

$$S\_HTechFrac\_ForInv = 1 - S\_LTechFrac\_ForInv \qquad (6.23)$$

$$S\_Inv = \mathrm{MIN}(S\_InvMax\_LTech, S\_InvMax\_HTech) \qquad (6.24)$$

The structure explained up to this point constitutes the backbone of the economy sector. Additional to these, some sub-structures are built for determining output-capital ratio and the fraction of capital allocated to each sector. These structures are explained in detail in the following section.

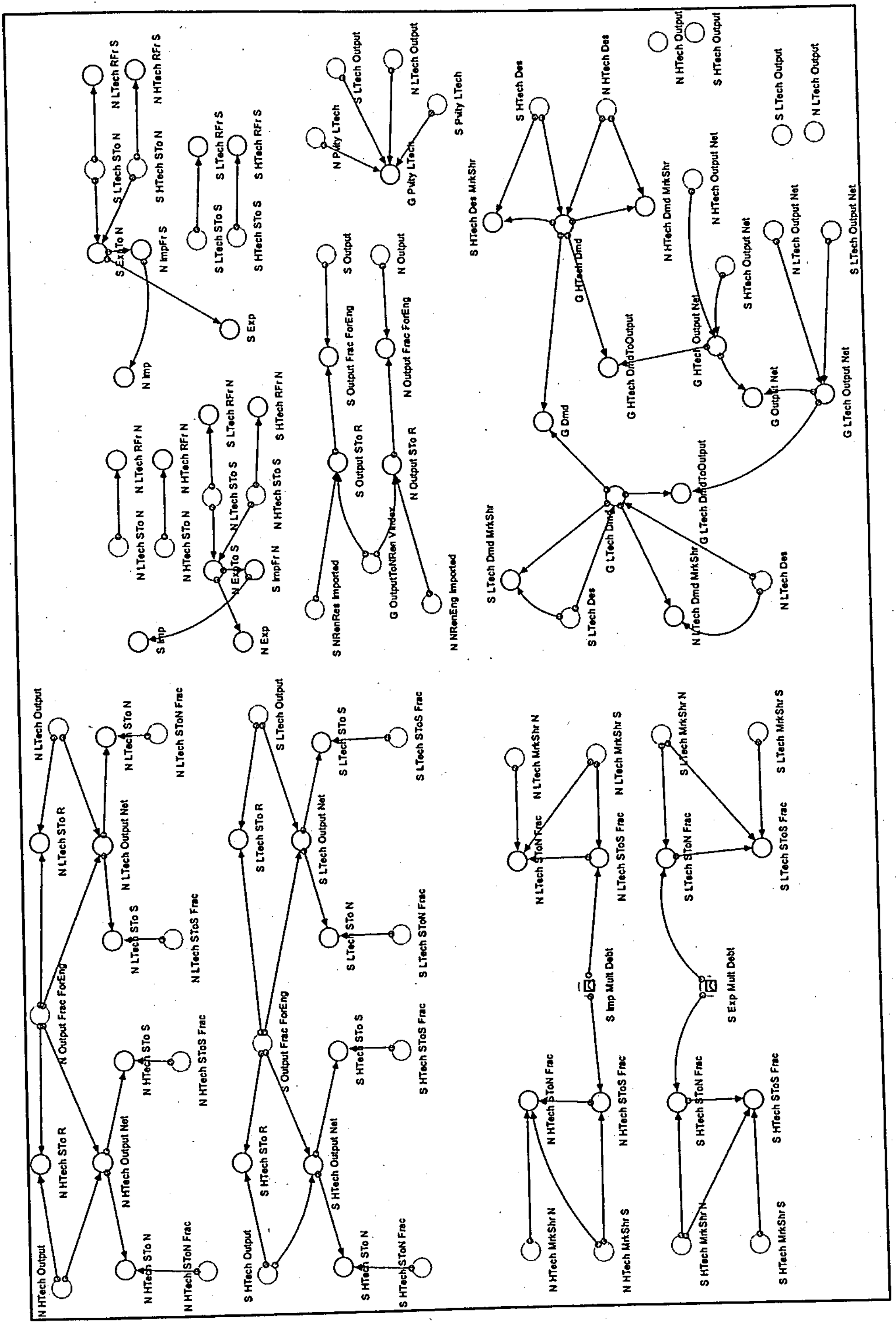


Figure 6.56. Stock-flow diagram for global market sector

6.3.3.1. The Structure Related to Determination of Output-Capital Ratio. In the model, output-capital ratio in any particular sector is assumed to be affected by capital embedded technology, labor embedded skill, and labor-to-capital ratio.

The variables that are hard or even impossible to quantify are represented by index variables, just indicating the current status with respect to a base year, which is 1975 in this model. One of such variables is labor skill, and it is represented as a stock variable in the model. It is assumed to be dominated by the learning-by-doing effect. Output generated per capita each period causes an improvement in labor skill. This variable constitutes the main affect changing the skill improvement flow. However, marginal return of further production per labor decreases as skill increases. This effect is incorporated with an affect dependent on the level of labor skill.

In order to incorporate the labor skill in the output-capital calculations, "effective labor" concept is introduced. This term represents the number of labor with skill level of 1975 required to generate the identical output a single labor with particular skill level can generate. In calculating the labor-capital ratios (*HTech_LabPerCap, LTech_LabPerCap*), it is the effective labor force (*LabForHTech_Eff, LabForLTech_Eff*) used in calculations. As a result, labor skill is indirectly incorporated into the mechanism used for calculating capital output-capital ratios.

The capital deepening effect is represented with the effect of labor-capital ratio on output-capital ratio (*PvityHTech_Mult_LPC, PvityLTech_Mult_LPC*). According to this effect from economics literature, output-capital ratio is assumed to decrease with decreasing labor-capital ratio (Spencer and Amos, 1993; Mankiw, 1999). This effect is also considered in *WORLD-3*, but it is assumed to be surpassed by technological improvements (Meadows *et al.*, 1974). The effect of a probable labor scarcity is incorporated via this effect. According to the formulation used in our study, it is guaranteed that output-capital ratio decreases to zero as soon as labor drops to zero. On the other hand, increase in output-capital ratio as response to increased labor availability is assumed to be diminishing and limited.

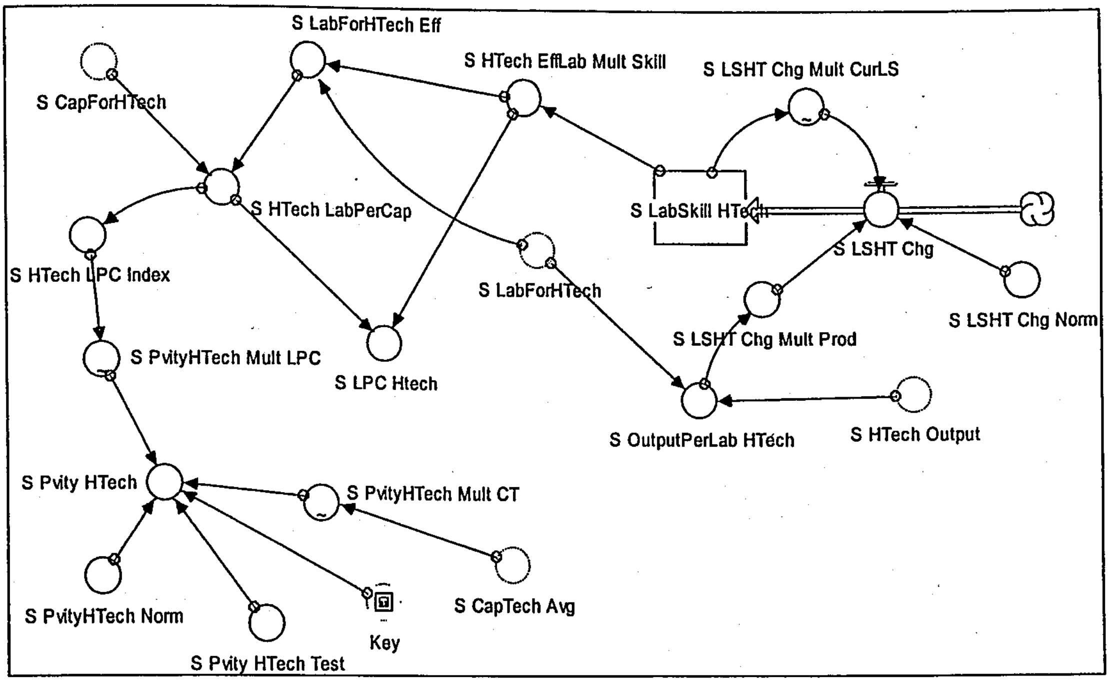


Figure 6.57. Stock-flow diagram for output-capital ratio

The final determinant of the output-capital ratio is the index of capital embedded technology (*CapTech_Avg*). As in the labor skill case, technology index represents the relative capability of capital in generating output with respect to the capital used in 1975. Technology development structure used in output-capital ratio is almost identical to the one used for renewable energy issue. New technology development increases with increasing per capita output, and marginal return of this increase in per capita output decreases as technologic level increases. New technology is assumed to be distributed after a long-delay, so there is a delay between the development of new technology and the time it becomes effective. A sample stock-flow diagram representing the determination of output-capital ratio in high-tech goods segment (*Pvity_HTech*) is presented in Figure 6.57.

Based on these three factors, output-to-capita ratio is determined by using an equation set similar to the one presented below, which is employed for determining the output-capital ratio of North in high technology goods production (*N_PvityHTech*);

$$N\_LabForHTech\_Eff = N\_LabForHTech \times N\_LabSkill\_HTech \qquad (6.25)$$

$$\mathit{N\_HTech\_LabPerCap} = \mathit{N\_LabForHTech\_Eff}/\mathit{N\_CapForHTech} \tag{6.26}$$

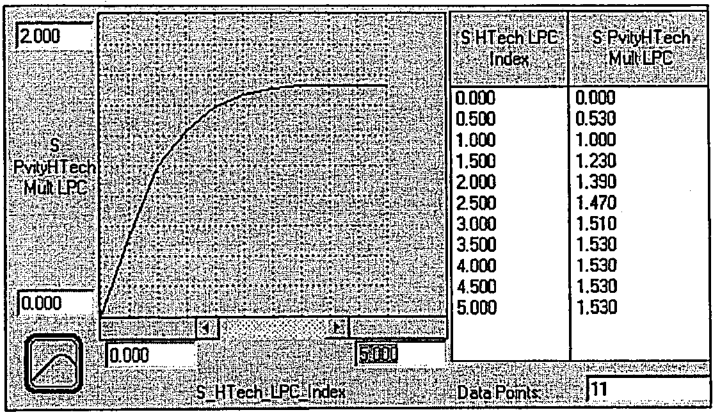
$$\mathit{N\_HTech\_LPC\_Index} = \mathit{N\_HTech\_LabPerCap}/\mathit{N\_Htech\_LabPerCap\_1975} \tag{6.27}$$

$$\mathit{N\_PvityHTech\_Mult\_LPC} = f(\mathit{N\_HTech\_LPC\_Index}) \tag{6.28}$$

$$\mathit{N\_PvityHTech\_Mult\_CT} = g(\mathit{N\_CapTech\_Avg}) \tag{6.29}$$

$$\begin{aligned} \mathit{N\_PvityHTech} = {} & \mathit{N\_PvityHTech\_Norm} \times \mathit{N\_PvityHTech\_Mult\_LPC} \\ & \times \mathit{N\_PvityHTech\_Mult\_CT} \end{aligned} \tag{6.30}$$

The function used in Equation (6.28) is defined as a graphical function and presented in Figure 6.58 (*f(N_HTech_LPC_Index)*).



S HTech LPC Index	S PvityHTech Mult LPC
0.000	0.000
0.500	0.530
1.000	1.000
1.500	1.230
2.000	1.390
2.500	1.470
3.000	1.510
3.500	1.530
4.000	1.530
4.500	1.530
5.000	1.530

Figure 6.58. Function used for defining the effect of labor-capital ratio on output-capital ratio

6.3.3.2. <u>The Structure Related to Capital Allocation between the Two Output Types.</u> As preferences of individual blocks for high and low technology goods may change over time, it is possible to observe short-term shortages and surpluses for specific goods in this market. In such cases, it is assumed that a capital shift takes place to balance the supply and demand. As mentioned in the assumptions section, long-run equilibrium of global supply and demand for a specific good is assumed to prevail. Based on this assumption, a capital shift between sectors is defined to balance the global demand as a response to changing demand. In real market, this shift is done via price changes affecting the profitability of a good type. However, instead of explicitly modeling these mechanisms, we assumed that these excluded mechanisms result in a capital shift.

A two-stock closed system is constructed to represent the fraction of capital allocated to each output type. In this structure each stock represents the fraction of capital allocated to production of a particular good type. These stock levels are manipulated through flows between them, which are initiated as a response to a shortage in an individual product type (see Figure 6.59).

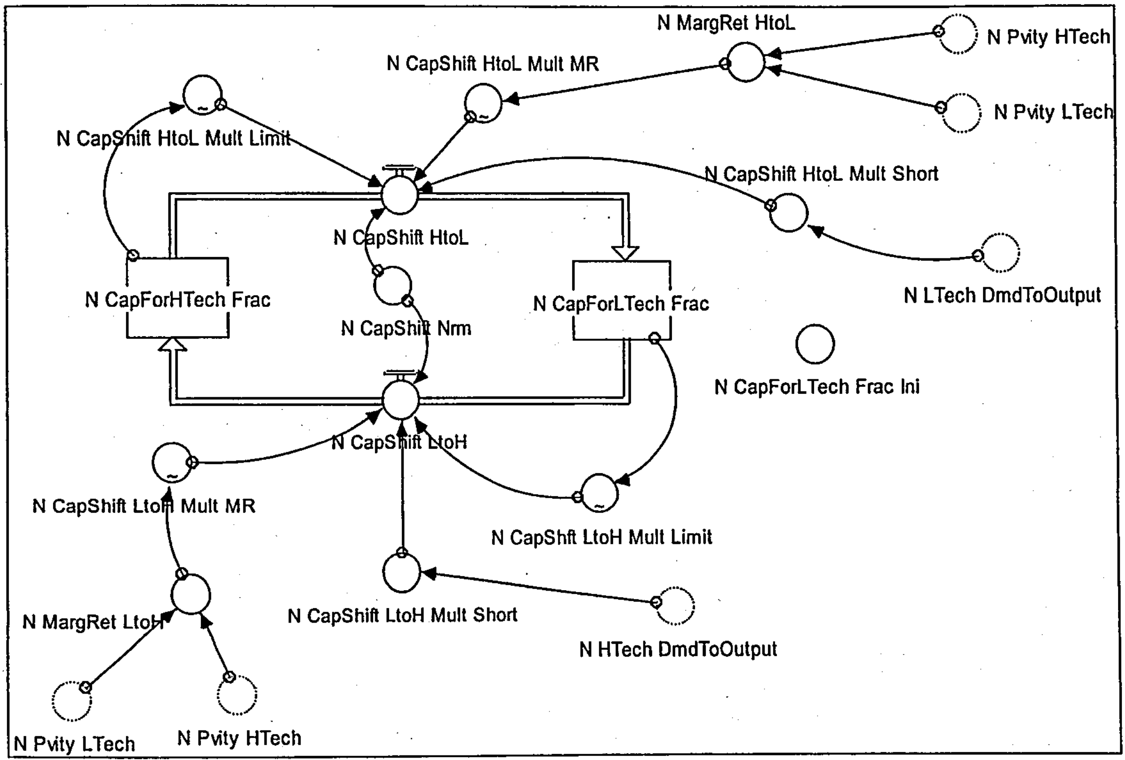


Figure 6.59. Stock-flow diagram for capital shifting structure

The rate of capital shift between output types is mainly determined by two factors. First of them is the magnitude of the shortage experienced; more severe the shortage, faster the capital shift. Other factor is the marginal gain in making such a shift. Two economies with different economic conditions should not be expected to react identically to any demand-supply distortion. It is logical to expect the block with the greatest advantage, to compensate the majority of the existing shortage. In the model, speed of the shift is calculated separately for the blocks and this speed is defined to be a function of marginal output increase obtained by shifting capital from one sector to another. In other words, difference between the output-capital ratios in different sectors is the main factor determining the transition speed. Block with the higher marginal return will have a faster shift, and consequently most of the shortage will be compensated by that block.

6.3.4. Dynamics of the Economic Activity Sectors in Isolation

All of the isolated runs for economic activity sector group are performed by relaxing the energy constraint, so that output is determined only by the capital, and constant population and labor force levels. Behaviors observed for capital stocks and economic output rate are given in Figure 6.60 and Figure 6.61, respectively. While capital stocks demonstrate an exponential growth behavior, output rates seem to follow close-to-linear paths.

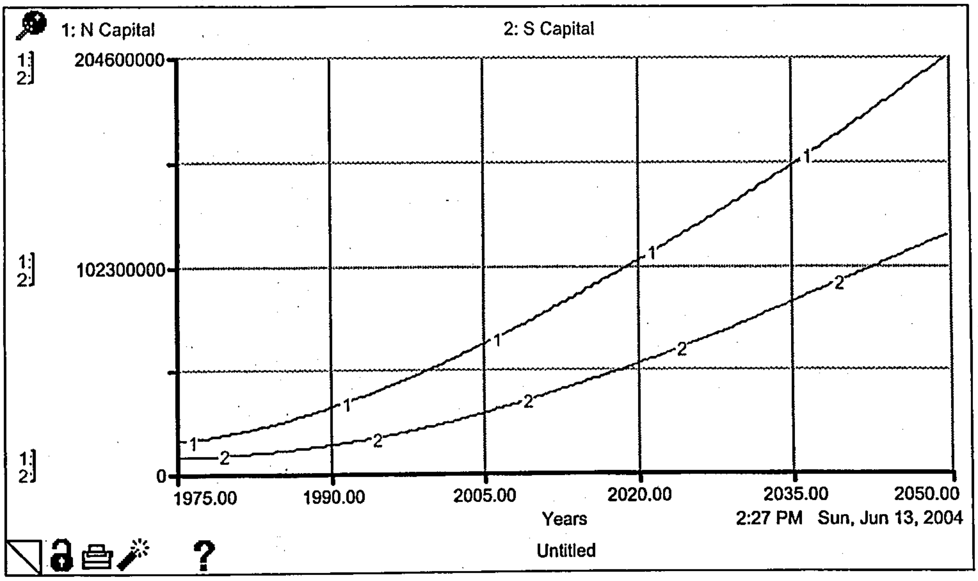


Figure 6.60. Capital stock levels in isolated economic activity sector run

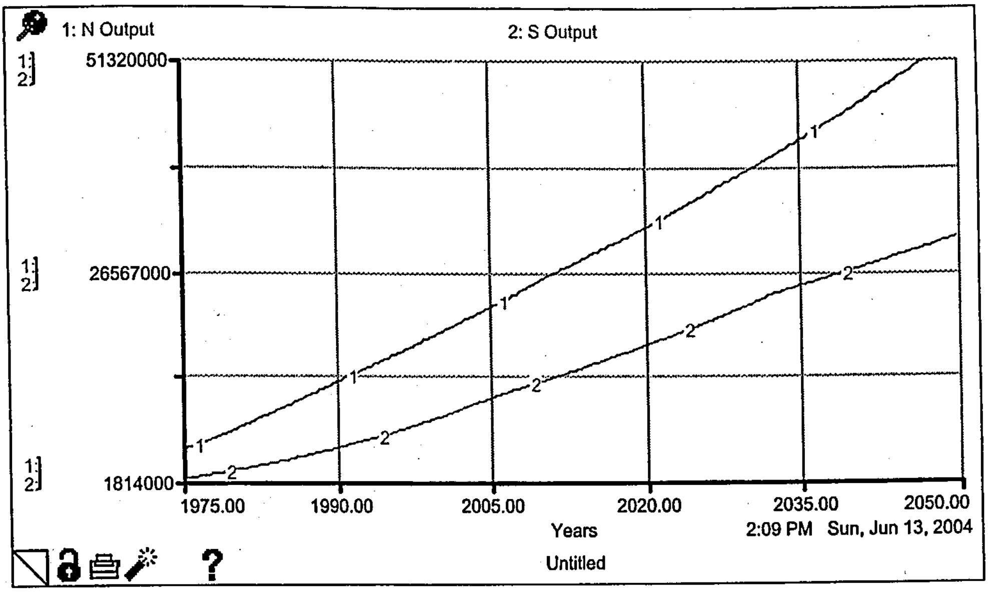


Figure 6.61. Economic output levels in isolated economic activity sector run

Discrepancy between the rates of change behavior observed in capital and output rate is primarily due to decreasing output-capital ratios. As population is constant, marginal return of additional capital decreases as capital accumulation continues. In the beginning, technological progress exceeds the effect of capital deepening and output-capital ratio increases for a while, but then decreasing marginal return of capital prevails due to limited labor availability.

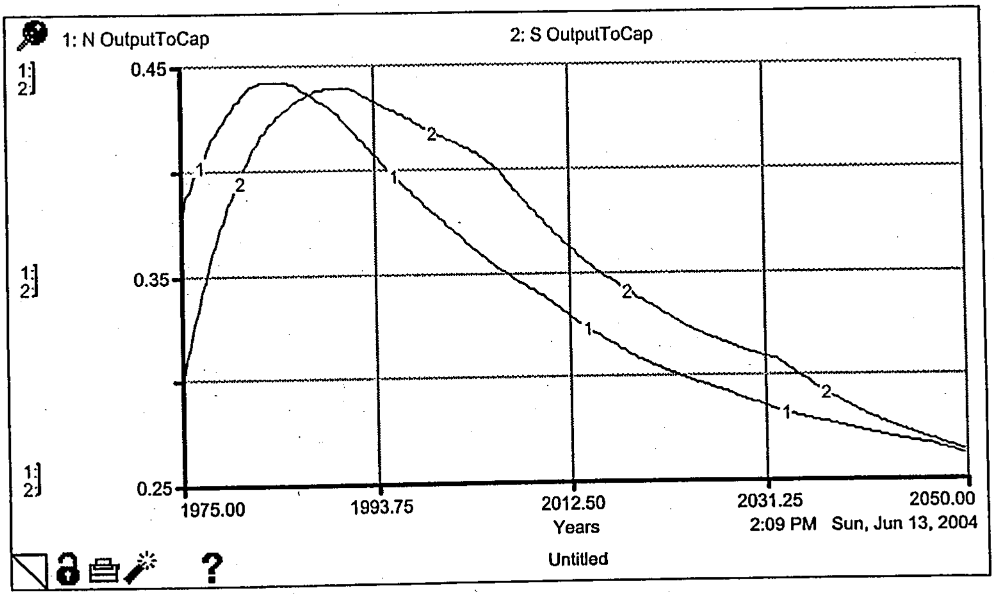


Figure 6.62. Output-capital ratios in isolated sector run

In the same isolated run, it is seen that parallel to the economic development of both blocks, global demand for high technology goods exceed demand for low technology goods (see Figure 6.63). As a response to this demand shift at the global scale, blocks are observed to shift their production capital to high technology goods sector, but with differing rates. Reactions of both blocks are driven by the demand-to-output ratios observed in these two sectors.

Finally, North block is observed to stay as the leading high technology goods supplier, whereas South increased its share and become the leading low technology goods supplier. This is primarily due to different reactions of blocks to changing demand patterns, as their output-capital ratios are different for different good types. The shares of output from each block in the global output of that good type are presented in Figure 6.65.

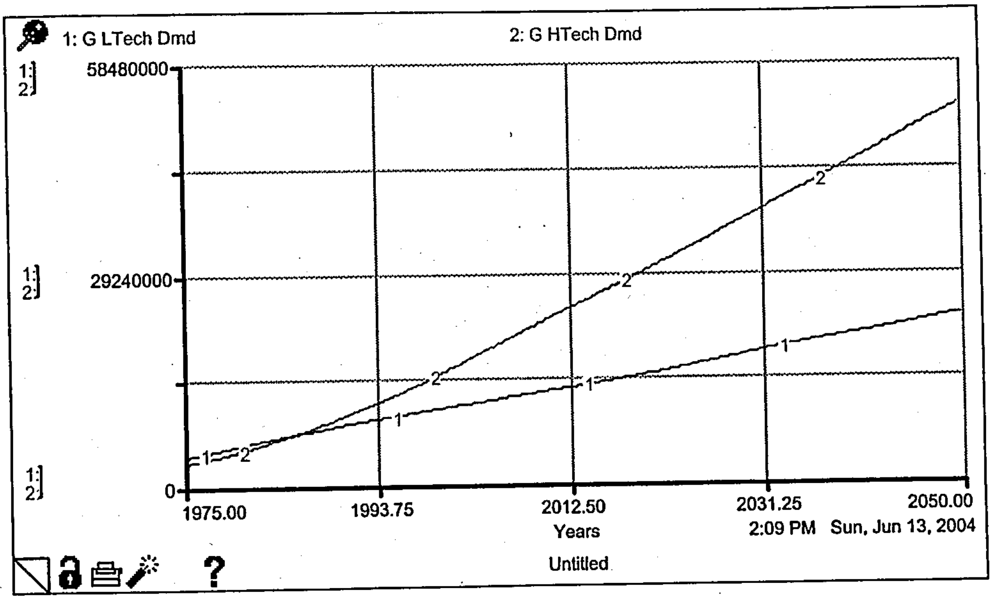


Figure 6.63. Global demand for low technology and high technology goods in isolated sector run

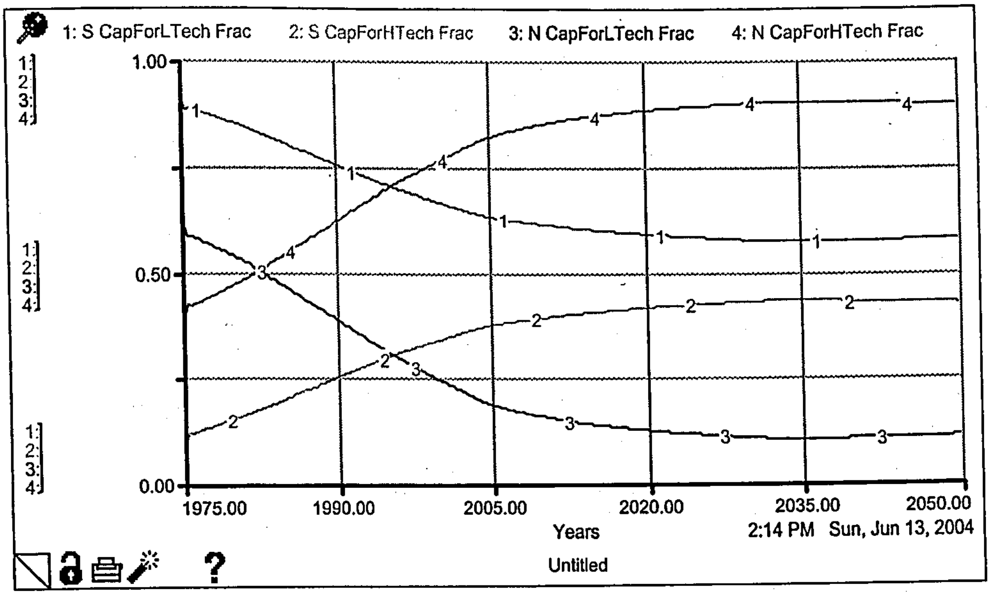


Figure 6.64. Fraction of capital allocated to the two sectors in isolated sector run

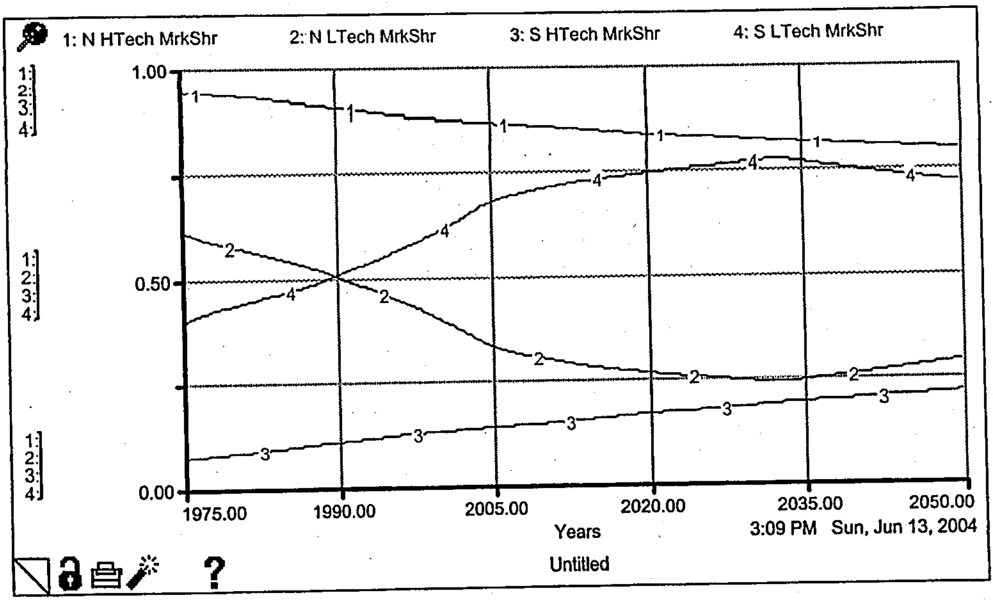


Figure 6.65. Market shares of blocks in the two sectors in isolated sector run

6.4. Pollution Sector

6.4.1. Background Information

Accumulation of the greenhouse gases in the atmosphere is one of most serious problems emerged after industrial revolution. Although several gases are classified to be a member of this group, gases constituting the most significant threat are carbon dioxide (CO_2), methane (NH_4), and nitrous oxide (NO_2). Emissions of these three gases sum up to almost 90 per cent of all greenhouse gas emissions (WRI, 2003; EIA, 2001).

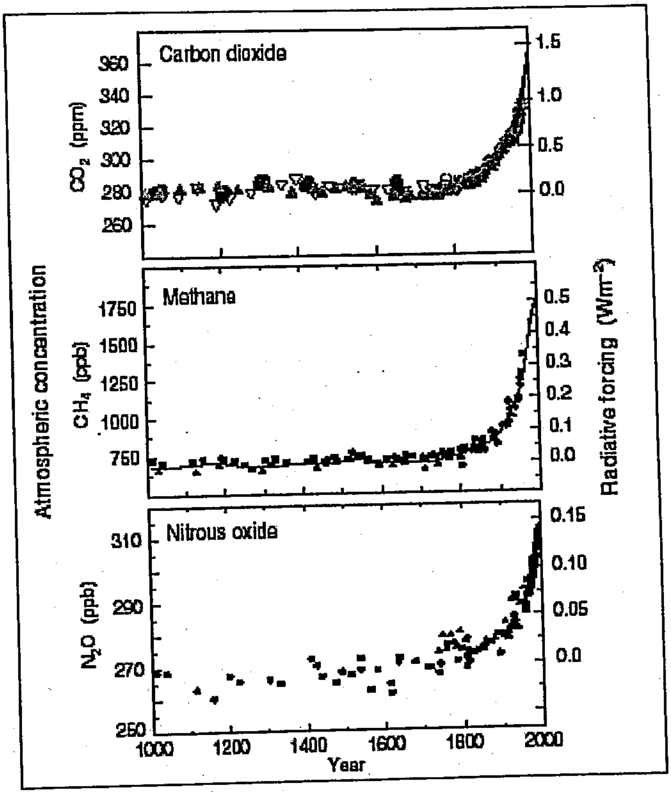


Figure 6.66. Changes in the atmospheric concentrations of three major greenhouse gases in the last 1000 years

Atmospheric concentrations of these three greenhouse gases increased significantly in the recent century as a consequence of anthropogenic emissions (see Figure 6.66). However, CO_2 constitutes the most severe threat with almost 50 per cent increase in its atmospheric concentration in less than 150 years.

As it was the common byproduct of fossil fuels, emissions of CO_2 demonstrated an exponential increase after fossil fuel-dependent industrial revolution (see Figure 6.67). Following this emission increase, atmospheric CO_2 concentration reached the level of 367 ppm in 1999 (IPCC, 2001). Significance of the increase in CO_2 concentration can be better understood by considering the fact that atmospheric CO_2 concentration was around 280 ppm for several thousand years (see Figure 6.66).

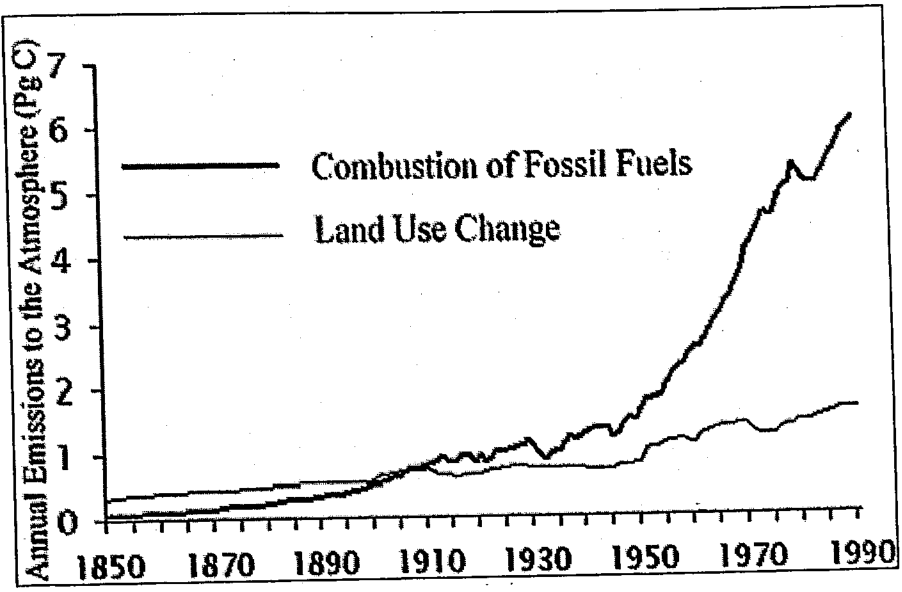


Figure 6.67. Annual CO_2 emissions in the period 1850-1990

Although CO_2 emissions change drastically, atmospheric levels seem to increase with a slower rate. This is mainly due to the internal dynamics of closed system called carbon cycle. Carbon cycle may be visualized as a closed system in which carbon circulates between four main sinks (stocks); atmosphere, oceans, geological reservoirs and land. These sinks, flows between them and magnitudes of these flows in GtC are given in Figure 6.68.

As it can be seen in Figure 6.68, the land uptake and emissions due to land-usage change are almost in balance. Based on that, net change in the atmospheric carbon levels seem to be mainly dependent on the discrepancy between the ocean uptake, and the anthropogenic carbon emissions as a result of fossil fuel burning and cement production.

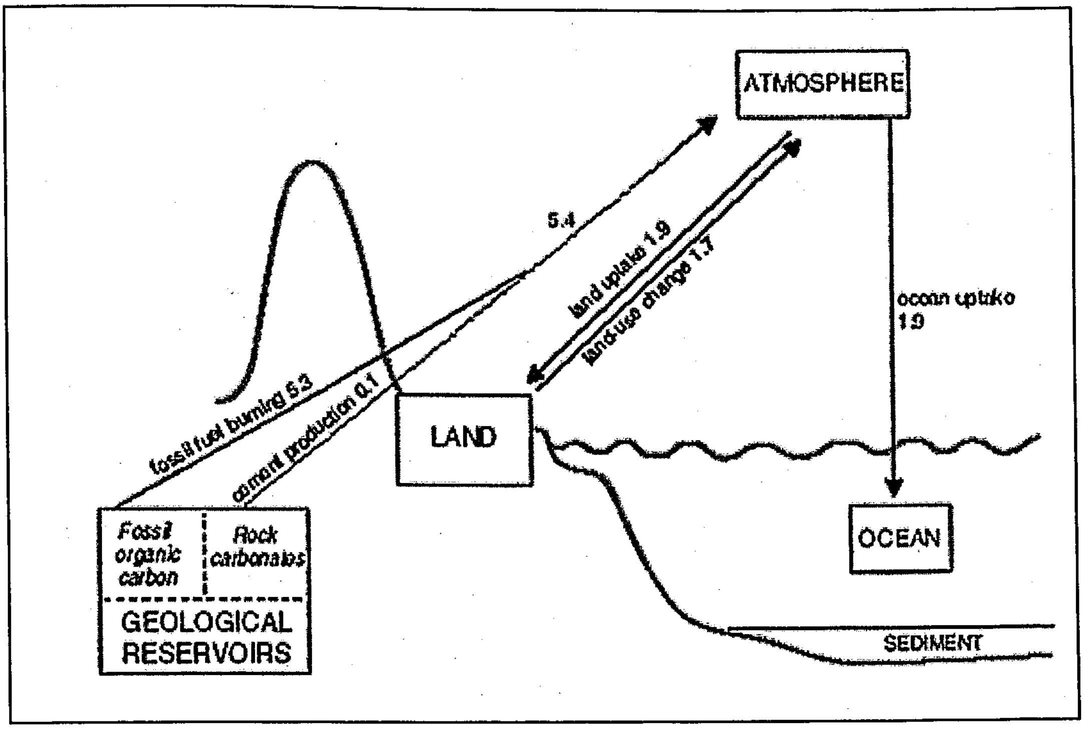


Figure 6.68. Sinks (stocks) of global carbon cycle and flows between them

While the magnitude of anthropogenic emissions is directly related to global fossil fuel usage, ocean uptake is theorized to be dependent on the atmosphere-ocean difference in CO_2 partial pressure. Additionally, fraction of anthropogenic CO_2 taken up by the oceans, decline with increasing amount of CO_2 dissolved in surface waters (IPCC, 2001; IEA, 2002c).

Due to the heterogeneous CO_2 distribution, oceans differ from atmosphere. Physical conditions like currents and the effects of living organisms differentiate the CO_2 concentrations dissolved in surface waters and depths of oceans. This structure makes it viable to dissolve much more CO_2 in the depths and employ them as sinks to dump CO_2, which is a crucial fact in keeping the global CO_2 at tolerable levels.

According to the business-as-usual scenario of IPCC, the atmospheric concentration of CO_2 is expected to double during the next 100 years (Watson, 2001). Considering that fossil fuel resources are estimated to contain 4000 GtC, compared to the quantity in the atmospheric reservoir of 750 GtC (IPCC, 2001; UNDP, 2000) there is the potential to raise atmospheric CO_2 levels several fold. At this point energy policies will have significant impact on determining the future CO_2 levels.

6.4.2. Fundamental Approach and Assumptions

Considering the variety of pollutants generated by global economic activity and the aggregation level used in this study, defining a pollution index to represent the global pollutant level and yearly emissions is a major difficulty. Instead of using an aggregated pollution index, it is decided to use a pilot pollutant to represent the general dynamics of pollution generation as a consequence of economic activity. Among several pollutants, greenhouse gases and more specifically carbon dioxide (CO_2), the dominant member of the group, is selected. The factors that support this choice are as follows; one of the reasons underlying this choice is the generality of the pollutant. CO_2 is a common by-product of a great variety of economic activities. On the other hand, it is possible to reach historical and recent data about the emissions and global levels of greenhouse gases, contrary to many pollutants. Finally, greenhouse gases are probably the most popular pollutant of the last two decades. Due to global warming threat, they are the second pollutant group after chlorofluorocarbons (CFCs) that attract such a wide attention in the international arena. Hence, they constitute a very good case study for the capabilities of global initiative against a pollution threat.

As mentioned in the previous section, CO_2 circulates between different systems of earth and this closed circulation system is referred as carbon cycle. Although carbon cycle is a closed-system, some of the flows between the major sinks of the system are too slow to be significant in the time horizon covered in this study. One of such flows is the carbon flux from deep oceans to surface waters. This process is approximated to have a delay of 1000 years (IPCC, 2001). On the other hand, flux from surface waters to deep oceans is much faster, such that its pattern is assumed to have significant impact on the CO_2 levels in surface waters and atmosphere. Hence it is covered in the model.

The other ignored flows are the geologic reservoir formation from the carbon in the deep oceans and carbon in the living organisms. Considering that oil formation is a typical example of such a flow, these flows are also ignored as their time-horizons are at the degree of thousand years.

Non-anthropogenic carbon fluxes from land-to-atmosphere and fluxes from atmosphere to land are assumed to in balance and their contribution to the long-term atmospheric carbon levels is assumed to be insignificant. So this sector mainly focuses on the CO_2 flows due to economic activity and CO_2 uptake by oceans, assuming that their relative magnitudes determine the patterns to be observed in atmospheric CO_2 levels.

6.4.3. Description of the Structure

As mentioned before, CO_2 pollution is defined to be a truly global problem, and it is modeled in a single sector belonging none of the blocks. The structure constructed in this sector aims to simulate the atmospheric CO_2 concentration dynamics as a result of CO_2 emissions caused by resource usage by the blocks and CO_2 absorption by oceans.

Stock flow diagram of the sector is given in Figure 6.69. Brief descriptions of the variables used in this sector are presented in Appendix B.

The structure used for this sector includes two stock variables (see Figure 6.69). One of these two stocks represents the atmospheric CO_2 level, and the other one represents the CO_2 level in the ocean surface. Inflows of the atmospheric CO_2 stock are determined by the amount of non-renewable energy resources consumed by country blocks and the carbon intensity of their resource mix. As members of the non-renewable energy resources group has different carbon intensities, different mixtures of these resources result in different CO_2 emissions. Carbon intensity variables (*Co2_Per_NRen*) for the blocks are defined as time-dependent exogenous variables. In defining the variables, 25-year data from *World Development Indicators 2003* (World Bank, 2003) is employed and the trends in Figure

6.70 are observed. Based on these trends, time-dependent carbon intensity variables are defined via graphical function, which can be seen in Figure 6.71, Figure 6.72, and Figure 6.73.

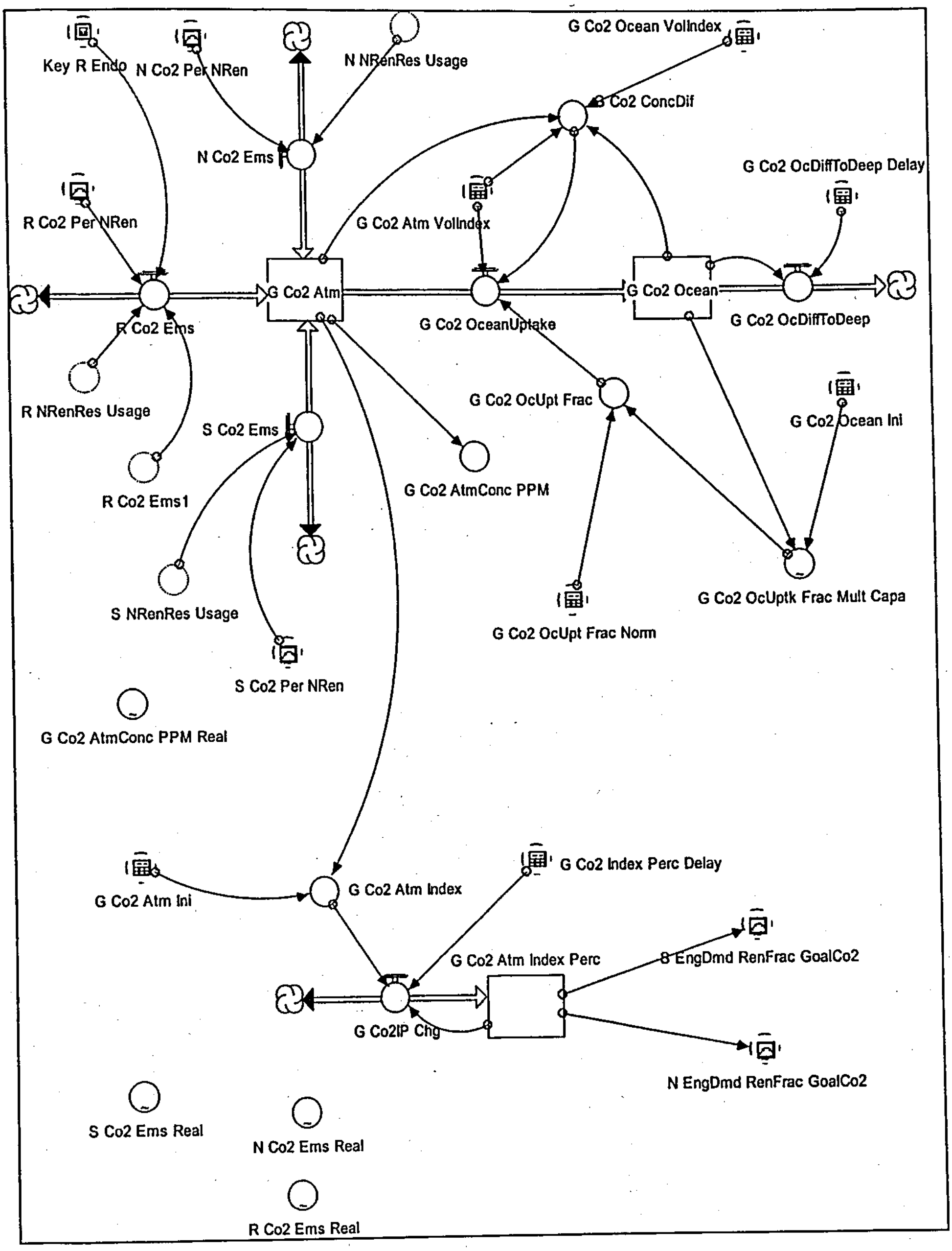


Figure 6.69. Stock-flow diagram for pollution sector

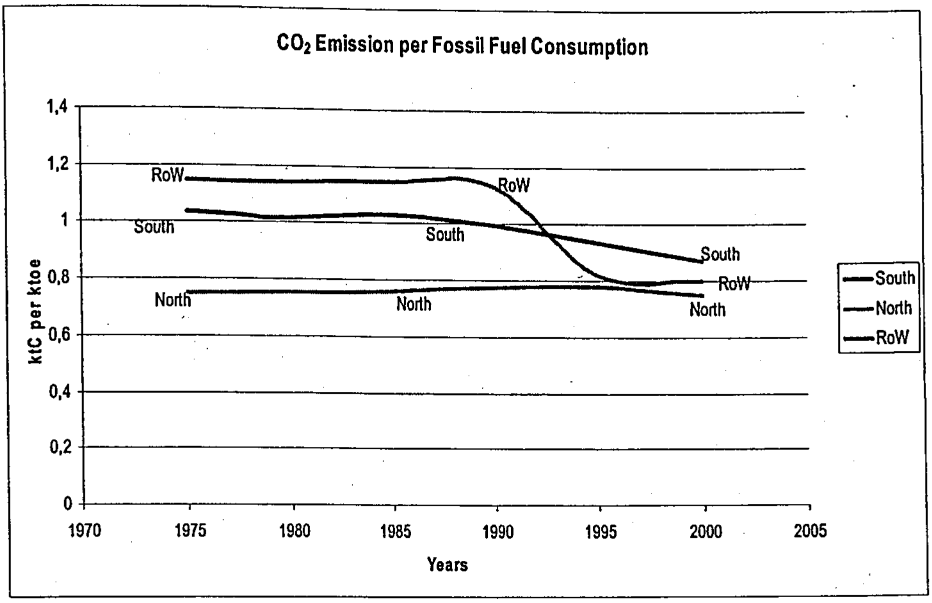
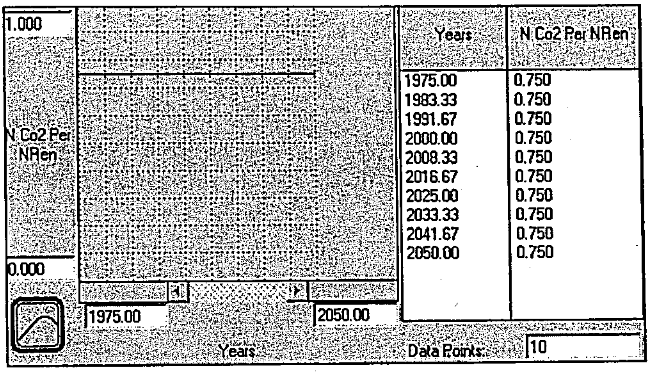


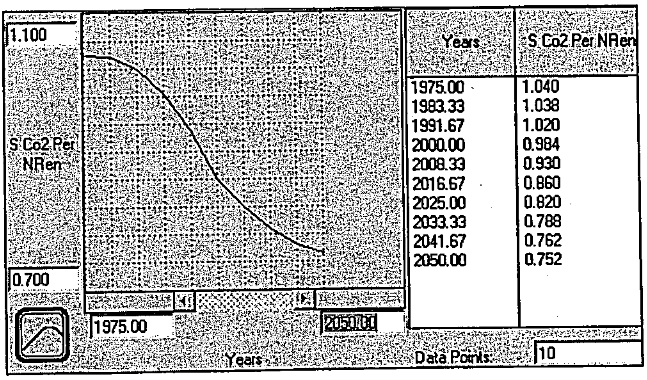
Figure 6.70. CO_2 emissions per fossil fuel usage



Years	N Co2 Per NRen
1975.00	0.750
1983.33	0.750
1991.67	0.750
2000.00	0.750
2008.33	0.750
2016.67	0.750
2025.00	0.750
2033.33	0.750
2041.67	0.750
2050.00	0.750

Data Points: 10

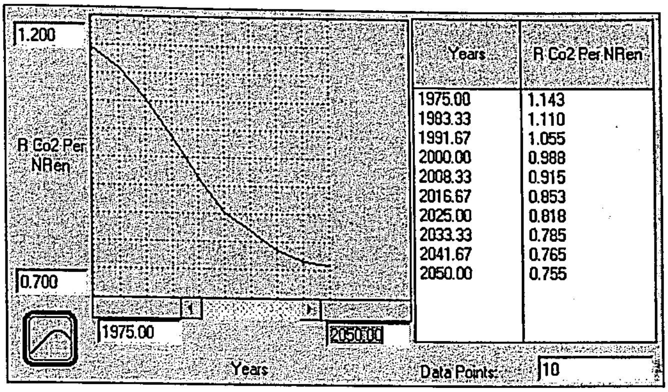
Figure 6.71. Co2_Per_NRen variable used for North



Years	S Co2 Per NRen
1975.00	1.040
1983.33	1.038
1991.67	1.020
2000.00	0.984
2008.33	0.930
2016.67	0.860
2025.00	0.820
2033.33	0.788
2041.67	0.762
2050.00	0.752

Data Points: 10

Figure 6.72. Co2_Per_NRen variable used for South

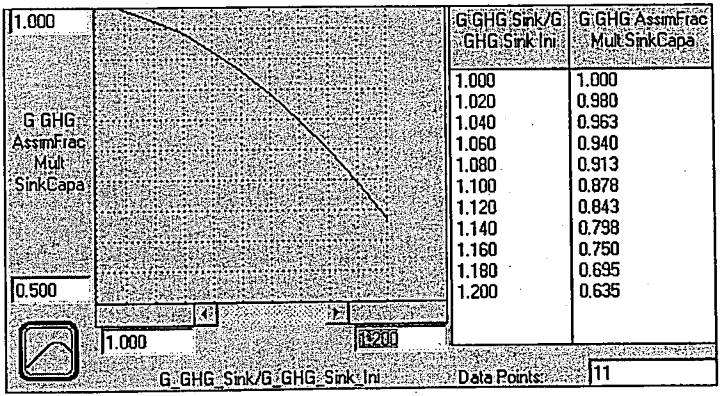


Years	R Co2 Per NRen
1975.00	1.143
1983.33	1.110
1991.67	1.055
2000.00	0.988
2008.33	0.915
2016.67	0.853
2025.00	0.818
2033.33	0.785
2041.67	0.765
2050.00	0.755

Data Points: 10

Figure 6.73. Co2_Per_NRen variable used for RoW

Single outflow from the atmospheric CO_2 stock is the CO_2 uptake by oceans (*Co2_OceanUptake*). This flow is formulized to be directly proportional to the difference between CO_2 concentrations in ocean and atmosphere. In each period, a certain fraction of this difference is assimilated by oceans. Instead of using a constant, this fraction is defined to be variable and dependent on the concentration of CO_2 in oceans. As depicted in IPCC report (IPCC, 2001), buffer capacity of oceans reduces by increasing CO_2 concentration and the fraction of assimilation decreases. This effect is formulated with a graphical function (see Figure 6.74) using the oceanic CO_2 concentration divided by its initial level in 1975 (*GHG_Sink/GHG_Sink_Ini*). This system is very similar to capacity-constrained growth systems in the system dynamics literature, and buffer capacity determines the ultimate capacity of oceans.



G GHG Sink/G GHG Sink Ini	G GHG AssimFrac MultSinkCapa
1.000	1.000
1.020	0.980
1.040	0.963
1.060	0.940
1.080	0.913
1.100	0.878
1.120	0.843
1.140	0.798
1.160	0.750
1.180	0.695
1.200	0.635

Data Points: 11

Figure 6.74. Effect of oceanic CO_2 concentration on assimilation fraction

The second stock of the structure is the CO_2 concentration in the ocean surface, as mentioned above. There exists a single inflow and a single outflow for this stock. The inflow is the CO_2 assimilation from the atmosphere, which is explained above. Outflow of this stock represents the diffusion of CO_2 from the surface waters to the largest global CO_2 sink; deep ocean waters. With the help of some mechanical, chemical and biological systems, CO_2 at the surface is pumped to deep waters. Although, the CO_2 in deep ocean returns back to surface after a delay, this delay is assumed to be around 1000 years (IPCC, 2001; IEA, 2002c). In formulating this flow, it is assumed that a certain fraction of CO_2 in the surface waters diffuse to the deep ocean each time period. Assuming that deep ocean has a carrying capacity much higher than the projected global CO_2 emissions, this diffusion fraction is assumed to be constant, differing from the former case.

Level of accumulations in both of the carbon sinks are represented with the mass of carbon that particular stock contains. In determining the flow between these sinks, which is directly related to concentration difference, these amounts are converted to a concentration index using volume indices for atmosphere and oceans. In setting the volume indices, we relied on the data from IEA (1999) stating that oceans and atmosphere were in balance long ago, when their carbon content were 1000 GtC and 600 GtC, respectively. Initially amount of carbon in the atmosphere is set to be equal to 710 GtC, and initial value of the oceanic sink is set to be 1030 GtC.

Causal-loop diagram in Figure 6.75 summarizes the causal relations embedded in this system. If oceanic CO_2 concentration increases, this causes a decrease in the concentration difference between oceans and atmosphere. As CO_2 flow to oceans is mainly driven by concentration difference, this causes CO_2 assimilation rate of oceans to decline. On the other hand, increased CO_2 in oceans affect the carbon buffer and absorption capability of oceans. So, a smaller fraction of concentration difference is absorbed by the oceans, as carbon dissolved in oceans increase. As in the former loop, this loop also acts in order to balance the change in oceanic CO_2 levels.

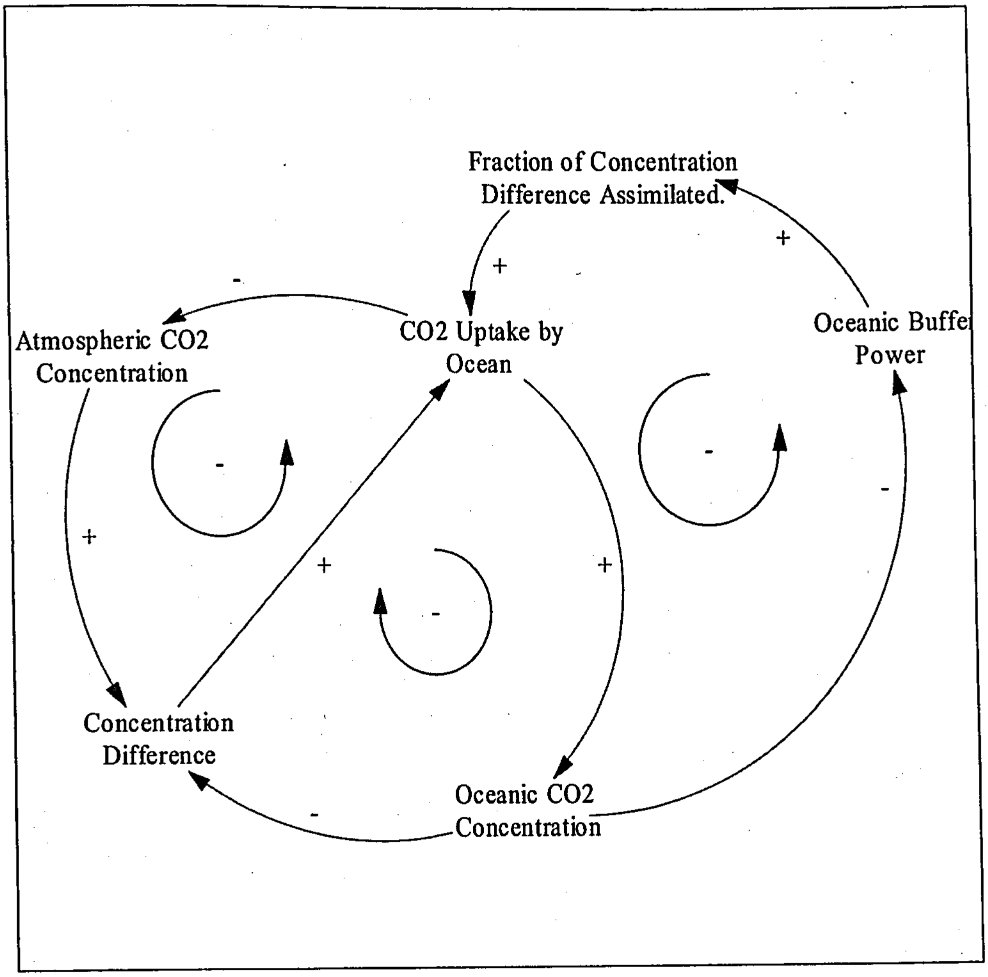


Figure 6.75. Causal-loop diagram for the oceanic CO_2 uptake mechanism

6.4.4. Dynamics of the Pollution Sector in Isolation

As in the former cases, the sector is isolated from other sectors and the behavior of the system covered by this sector is studied. For this sector, two main components, atmospheric and oceanic carbon sinks, are studied separately.

By using constant CO_2 emissions rate of 3.5 GtC per year, carbon level in the atmospheric sink demonstrates a growth behavior with a slightly decreasing rate of change. Accumulated CO_2 in the atmosphere yields an increase in the difference between partial pressures of CO_2 in oceans and atmosphere (see Figure 6.77). This increase in turn increases the amount of CO_2 flow from atmosphere to oceans. Consequently, the net rate of change in the CO_2 flow to atmosphere stays positive, but its magnitude slightly decreases in time.

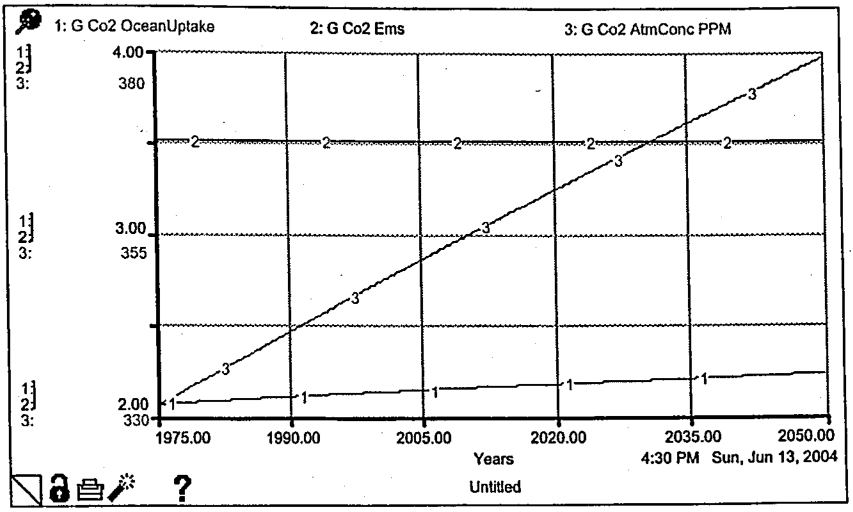


Figure 6.76. Atmospheric carbon sink and related flows in isolated sector run with constant emissions

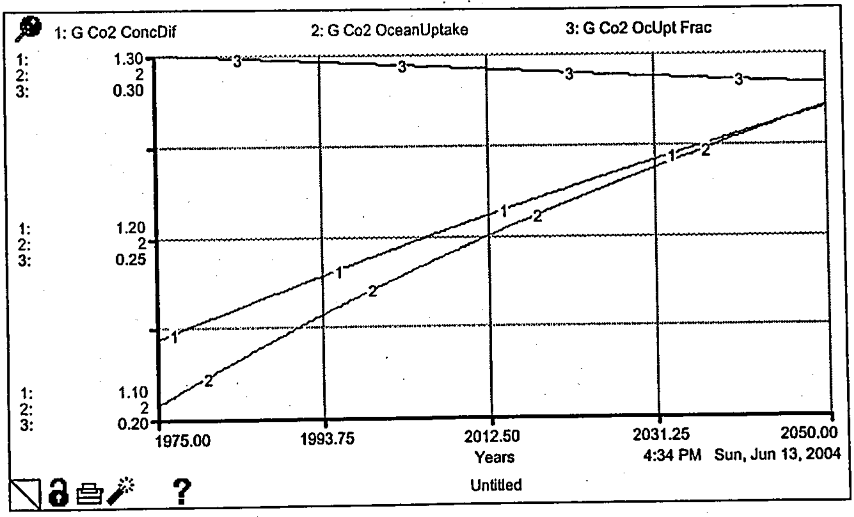


Figure 6.77. Factors affecting the CO_2 uptake rate of oceans in isolated run with constant emissions

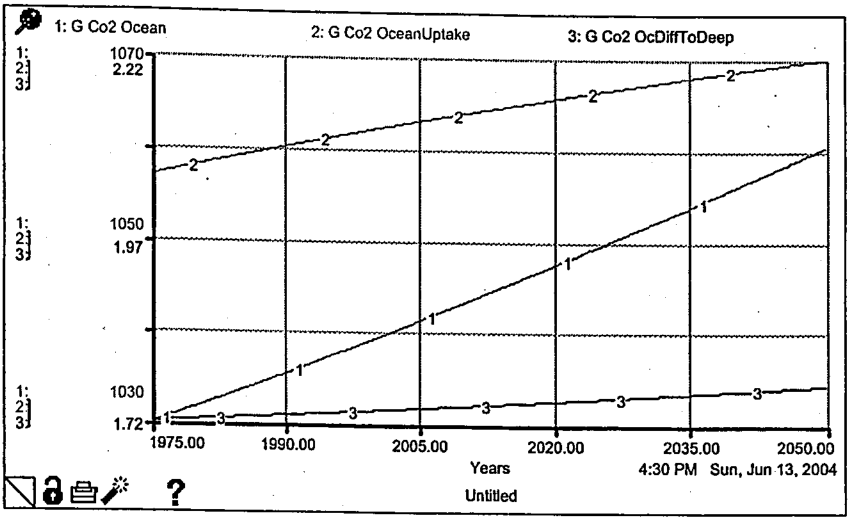


Figure 6.78. Oceanic carbon sink and related flows in isolated sector run with constant emissions

Behavior observed in the carbon content of the oceanic sink is also a growth behavior, but net rate of change is close to constant (see Figure 6.78). Inflow to the sink is the amount of CO_2 absorbed from atmosphere and due to increased concentration difference this flow demonstrates a growing behavior. Outflow from the sink is proportional to the amount dissolved in oceans and this also increases in time as carbon content of oceanic sink increases. Changes observed in flows seem to be close in magnitude such that net rate of change for oceanic sink stays close to constant.

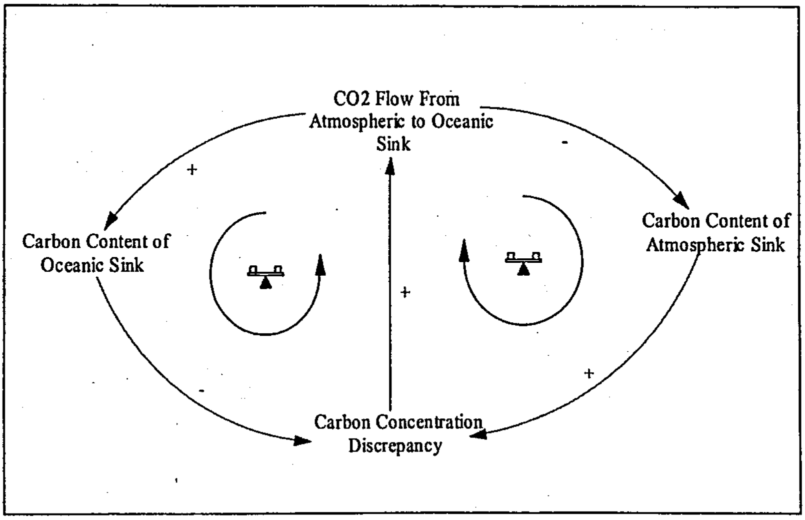


Figure 6.79. Balancing feedback loops of the carbon sinks

Behaviors of both sinks are dependent on the interplay of two flows associated with those sinks. For each sink, these are balancing feedback loops between one of the flows and the sink itself. Hence, unless conditions are manipulated, both sinks are expected to reach equilibrium.

Similar isolated runs are performed using variable global emission rates, which gradually increases to 9 GtC level from its initial value of 3.5 GtC. In this case, atmospheric CO_2 content is observed to increase exponentially, as increase in the CO_2 flow to oceans fail to match the increase in the emissions. Hence, the net rate of change in atmospheric CO_2 level is increasing over time (see Figure 6.80).

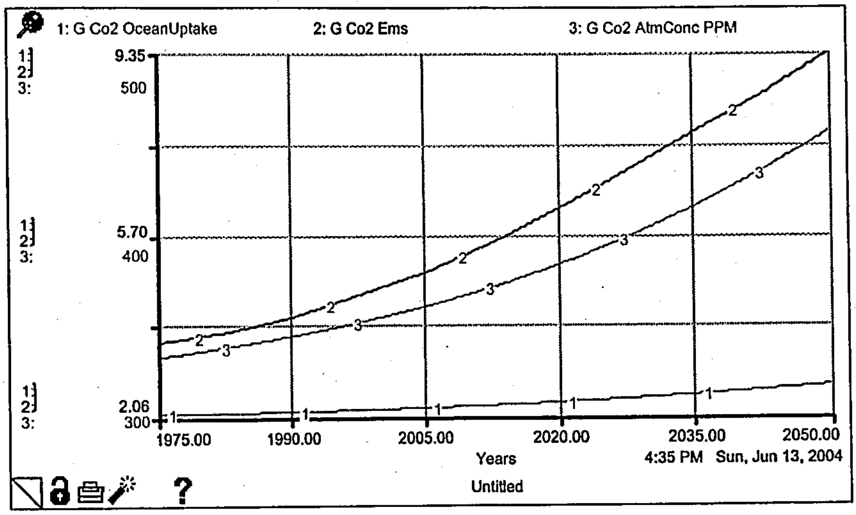


Figure 6.80. Atmospheric carbon sink and related flows in isolated sector run with increasing emissions

Dynamics observed for oceanic sink is very similar to the dynamics of atmospheric sink. Outflow from the sink increases, but this increase is very low compared to the increase in the inflow of this sink; CO_2 dissolved from atmosphere. Hence, oceanic sink also has an increasing net rate of change.

As mentioned above, an increase in the CO_2 flow from atmosphere to oceans is observed. This increase is mainly due to increased concentration difference. However, the rate of change in the flow is below the rate of change observed in the concentration difference. Increasing amount of CO_2 dissolved in oceans decreases oceans' capability to dissolve more, so fraction of concentration difference absorbed by oceans decreases over time (see 3rd line in Figure 6.82).

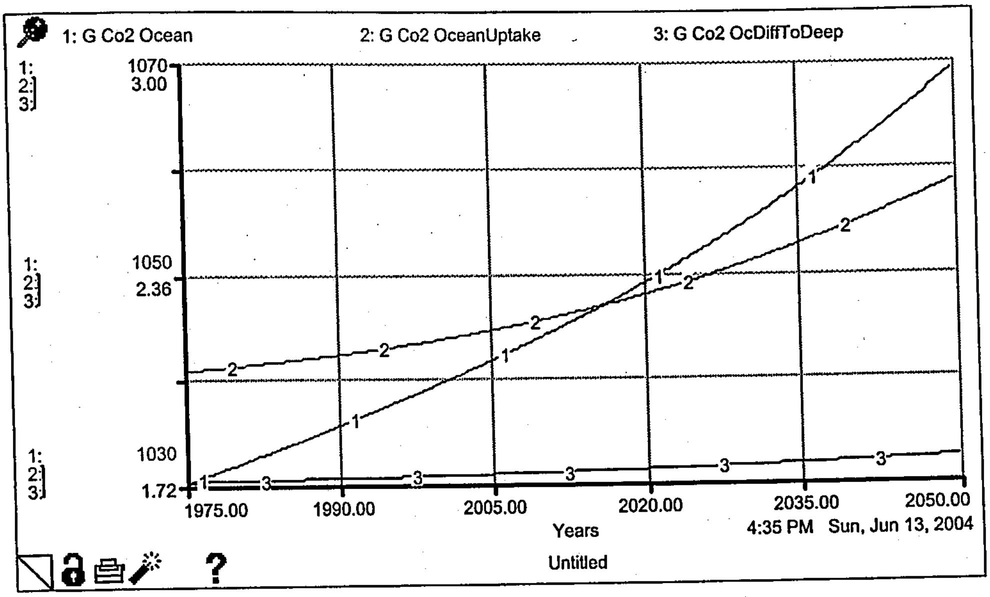


Figure 6.81. Oceanic carbon sink and related flows in isolated sector run with increasing emissions

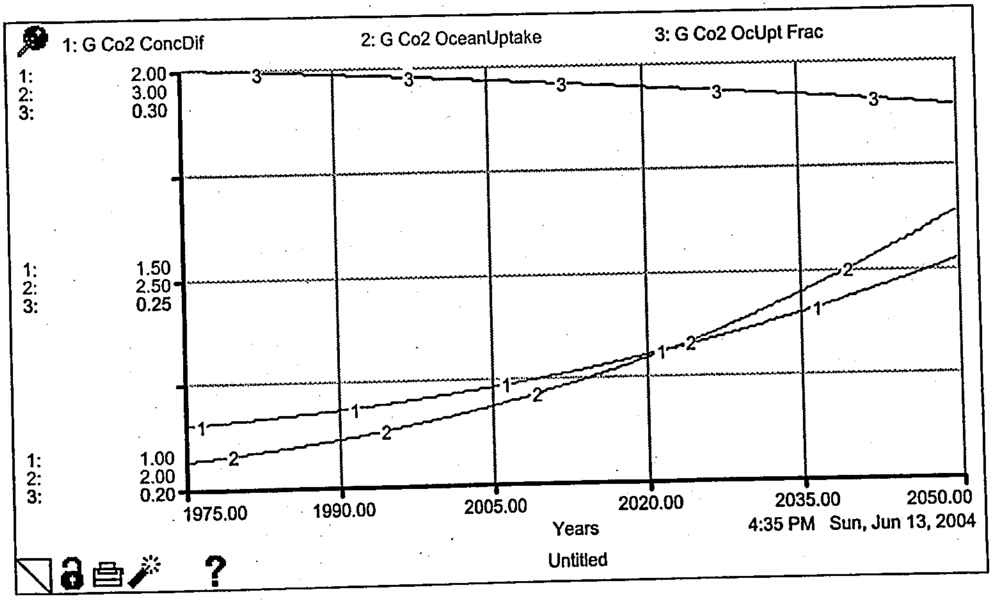


Figure 6.82. Factors affecting the CO_2 uptake rate of oceans in isolated run with increasing emissions

7. MODEL VALIDATION AND SENSITIVITY ANALYSIS

The aim of this chapter is to demonstrate the results of the experiments conducted in order to test the validity of the model built in this research. As mentioned in the methodology section, the accuracy of a system dynamics model behavior is meaningful only if there is sufficient degree of confidence in the model structure. Hence, before checking the behavioral validity of the model, a formal validation procedure is followed in order to detect structural flaws (Barlas, 1996; Forrester and Senge, 1980). In the behavioral validity tests, following the "structure-oriented behavior tests", emphasis is on the pattern prediction rather than point prediction, mainly because of the long time horizon and the aggregation level of the model.

The validation of the model is demonstrated on the basis of sector isolated and total runs of the model, concentrating on the "structure-oriented behavior tests" proposed in literature, such as extreme condition and behavior sensitivity tests. Finally, the model behavior for the period 1975-2000 is compared with real data, as long as reliable data are available.

7.1. Validity Testing of Sectors

7.1.1. Population Sector Group Validity Testing

The structure of the isolated population sector is tested under extreme fertility values. In the first run presented in Figure 7.1, fertility is set to zero per woman. All three population groups and total population converge to zero-level in the long-run. As expected, pre-reproductive population group is the first population group to start decreasing. Oldest group of the population demonstrates a boom-then-bust behavior, consistent with the expectations. The structure also demonstrates the expected rapid exponential growth behavior with an extremely high fertility value of 10 per woman, which can be seen in Figure 7.2.

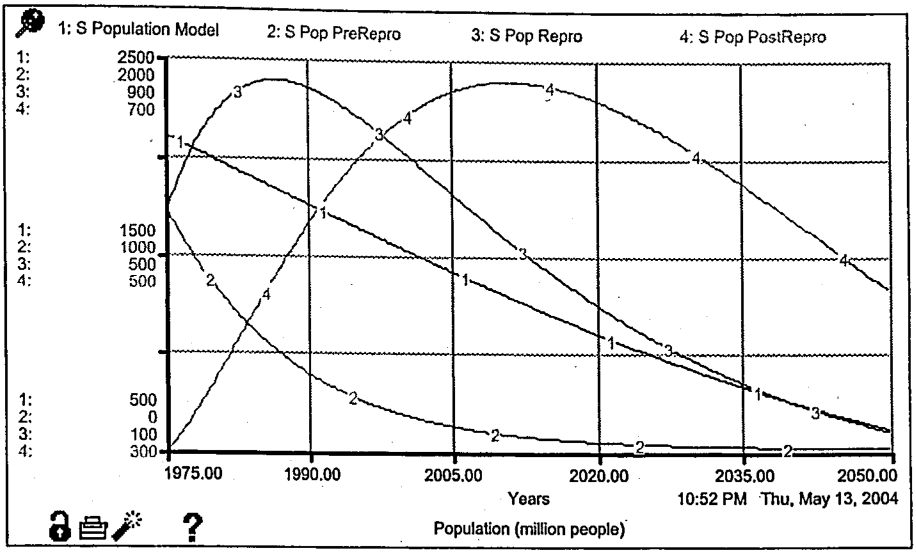


Figure 7.1. Population dynamics with average fertility set to zero per woman

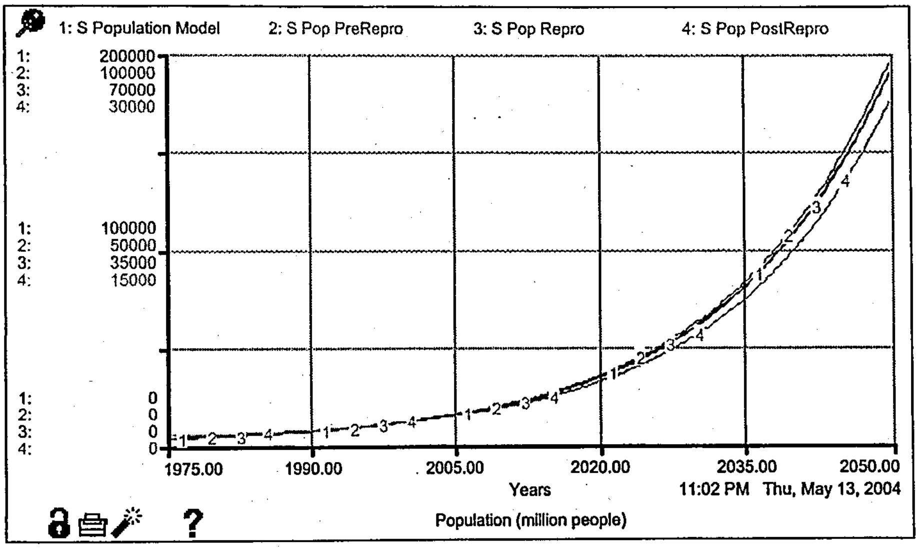


Figure 7.2. Population dynamics with average fertility set to 10 per woman

The sector is also tested under extreme age-composition conditions. Population demonstrates the behavior in Figure 7.3, when a population composition with a high median age is introduced. On the other hand, an initially young population composition results in the behavior given in Figure 7.4. Considering the replacement level fertility used, decreasing population in the first instance and population growing with a decreasing rate in the second instance are consistent with the expectations.

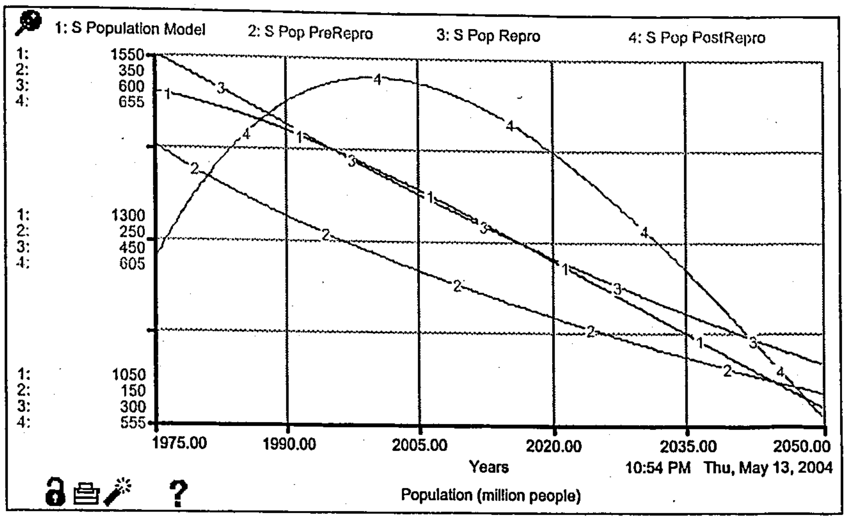


Figure 7.3. Population behavior with old median age

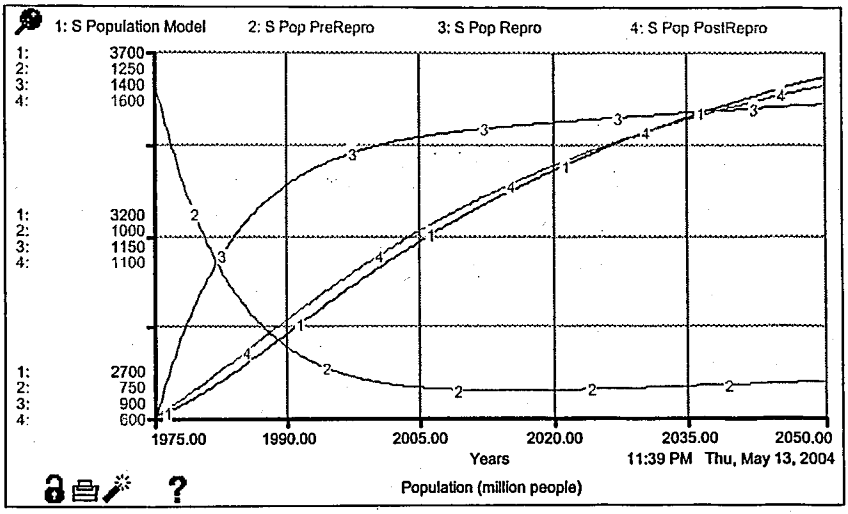


Figure 7.4. Population behavior with young median age

Finally, the model behavior related to urbanization is tested under extreme condition. By definition, the fraction of urban population should be less than or equal to 1, and urbanization process is expected to demonstrate a growth with a decreasing rate. In order to test the model behavior with respect to these expectations several extreme population density and income per capita figures are used. In these runs, it is seen that even with extreme input values that are expected to accelerate urbanization; urban population fraction generated by the model does not exceed value 1, independent of the initial value. Behavior of the fraction of urban population with initial urban population fractions of 1, 0.95, 0.5 and 0 are presented in Figure 7.5.

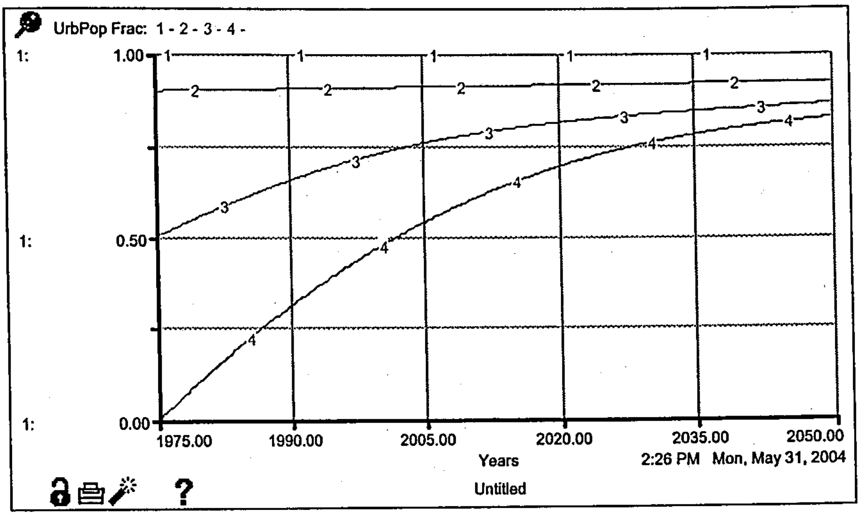


Figure 7.5. Model generated urban population fraction with initial urban population fraction values of 1, 0.95, 0.5 and 0

To conclude, the structure of the population sector in isolation is found to be logically valid, as a result of a set of simulation tests under extreme conditions.

7.1.2. Energy Resources Sector Group Validity Testing

In the sector-isolated runs, the behavior of the sector in determining the renewable energy demand is tested by manipulating the reserve-demand ratio, which is the resource availability indicator used in the model. As an extreme case, a constant reserve-demand ratio of 100 is tested. The system generates the renewable energy demand fraction as seen in Figure 7.6. Considering that a reserve-demand ratio of 100 indicates that reserves are enough to supply resources for 100 years with the current usage rate, a shift to renewables should not be expected, as the sector is isolated from pollution related feedback. The model generated behavior is consistent with these expected behaviors.

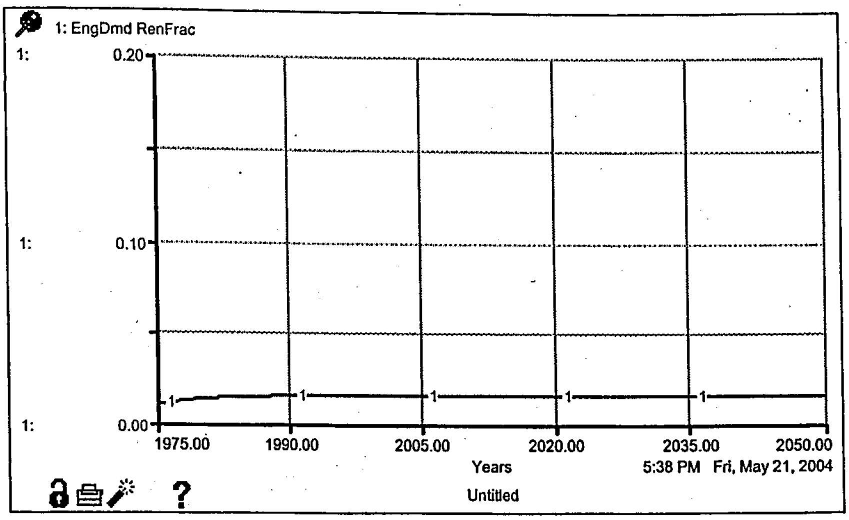


Figure 7.6. Renewable energy demand fraction with reserve-demand ratio for non-renewable resources set to a constant value of 100

As a second case, reserve-demand ratio is defined to be zero initially. Model generates a fast demand shift to renewables as seen in Figure 7.7. Considering the adaptations required for shifting the energy demand, a 15-year transition is logical and even fast for a block initially dependent on non-renewable energy resources. Dynamic behavior generated is normal and consistent with expectations.

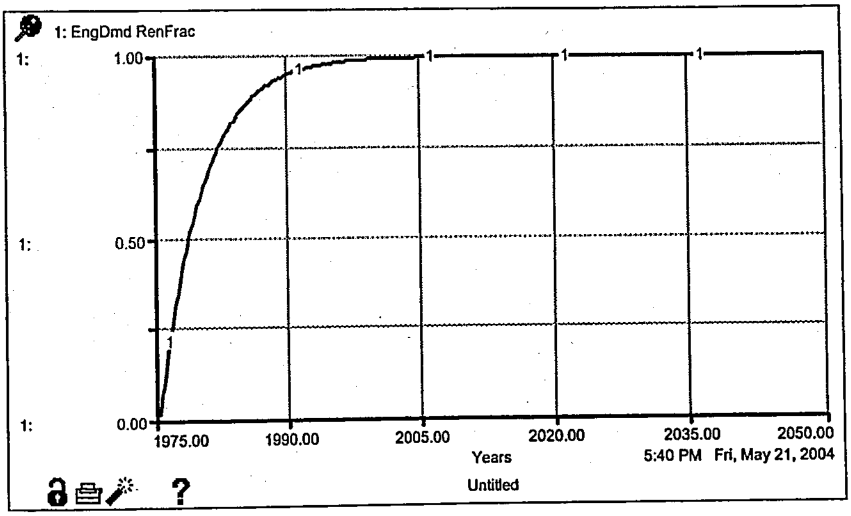


Figure 7.7. Renewable energy demand fraction with reserve-demand ratio for non-renewable resources set to a constant value of zero

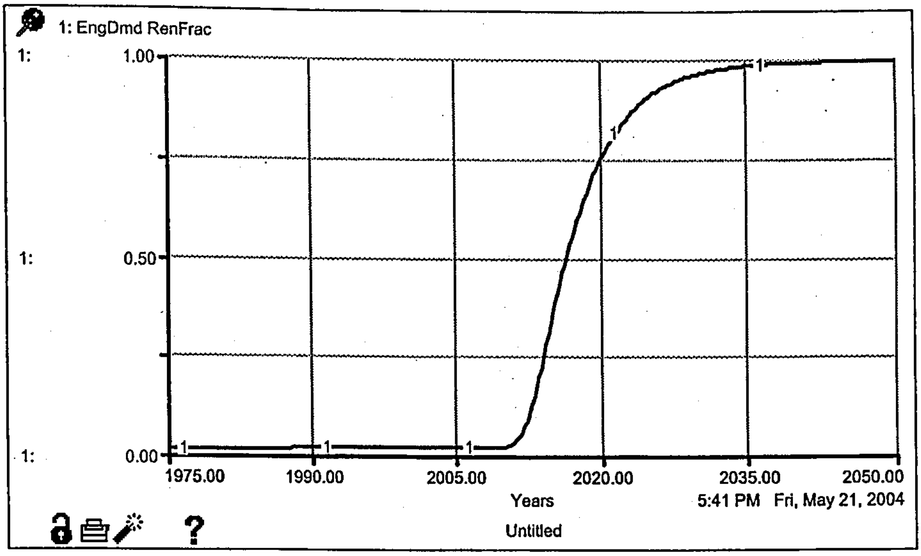


Figure 7.8. Fraction of energy total energy demand directed to renewables with reserve-demand ratio changing from 100 to zero instantaneously

Extreme value tests are also applied to structure generating the capital productivity in renewable energy production (*RenEngPerCap*). In the first instance, output per capita and reserve-demand ratio for non-renewables are set to be constant. In such a case, there will be no extra motivation for increasing R&D activity, as there is no change both in welfare or resource scarcity risk. Expected behavior was a slow increase in productivity, due to normal rate of technology improvement (see Figure 7.9).

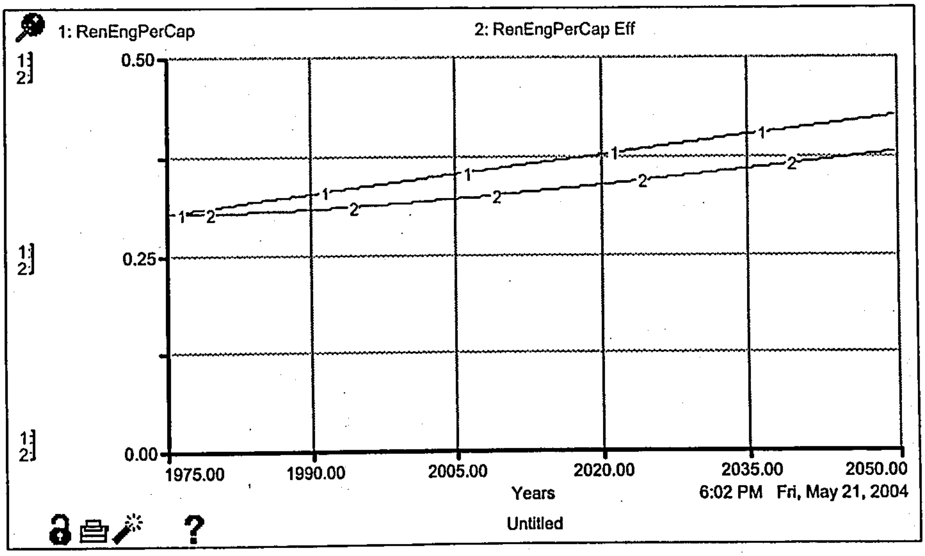


Figure 7.9. Change in renewable energy generated per capital, under constant per capita income and reserve-demand ratio for non-renewables

The changes in the capital productivity in renewable energy generation is also tested with constant reserve-demand ratio (*NRenRes_ResvToDmd*=40) and extremely high output per capita index (*OPC_Index*=100), and with extremely low reserve-demand ratio (*NRenRes_ResvToDmd*=0) and extremely high output per capita index (*OPC_Index*=100) values. In both cases rapid improvements are expected, the second case representing the fastest improvement. The model behavior for the first case is given in Figure 7.10, whereas the plot for the second case is given in Figure 7.11

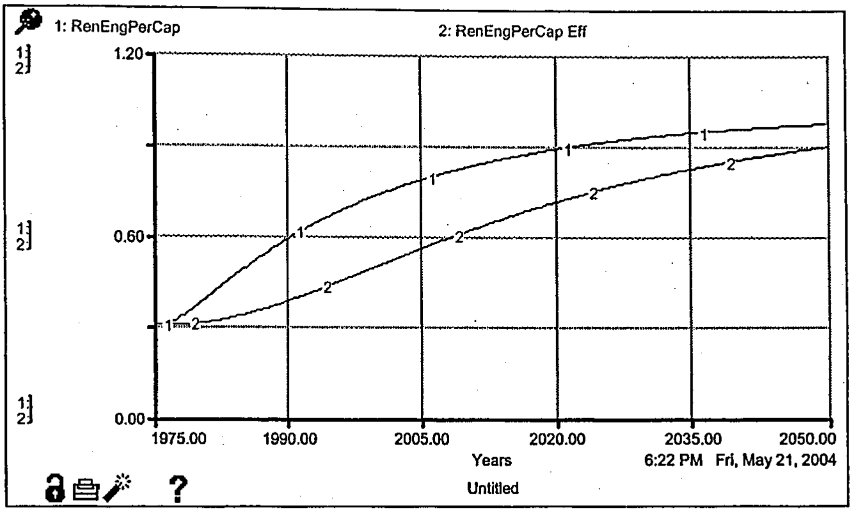


Figure 7.10. Change in renewable energy generated per capital, under high per capita income and constant reserve-demand ratio for non-renewables

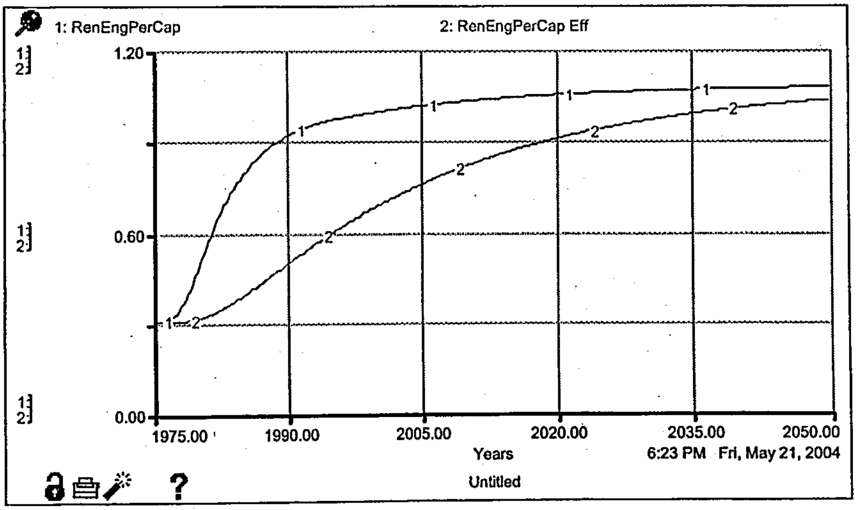


Figure 7.11. Change in renewable energy generated per capita, under high per capita income and low reserve-demand ratio for non-renewables

While testing the non-renewable resource production and discoveries, four extreme cases are tested. In all four of these tests, a constant resource demand is used. Reserves are defined as multiples of this constant demand. Reserve values used in these cases are given in Table 7.1.

Table 7.1. Initial values for discovered and undiscovered reserves used in four extreme value tests

Case No	Discovered Reserves (in multiples of demand)	Undiscovered Reserves (in multiples of demand)
1	10	500
2	10	10
3	100	100
4	100	10

In case 1, as a consequence of extreme amount undiscovered reserves, a high discovery rate resulting in a rapid increase in discovered reserves is observed, in the first phase of the simulation. Following this increase, which yields a reserve-demand ratio of almost 120, discovery activities slow down and discovered reserves stay almost constant. Outcomes are logical, assuming that in a resource-abundant environment, there will be no motivation towards conducting resource exploration for further reserve discoveries. Output regarding discovered and undiscovered reserves, the reserve discovery rate, and the reserve-demand ratio are given in Figure 7.12 and Figure 7.13.

In case 2, both discovered and undiscovered reserves are defined to be very low; they can support a 20 year demand if totally used. In the model output, it is seen that none of these reserves are completely depleted in a 75-year run, but gradually converge to depletion level (see Figure 7.14). As it is assumed that outflows from these reserves (resource production from known reserves and reserve discovery from undiscovered reserves) are dependent on the fraction of reserves remaining, it is consistent to have gradually decreasing production and discovery rates. As a result, the behavior generated by the model is consistent with the assumptions regarding reserve discovery and production. It is also important to note that as resource production capacity decays, resource shortage prevailed in this case after some point in the simulation run.

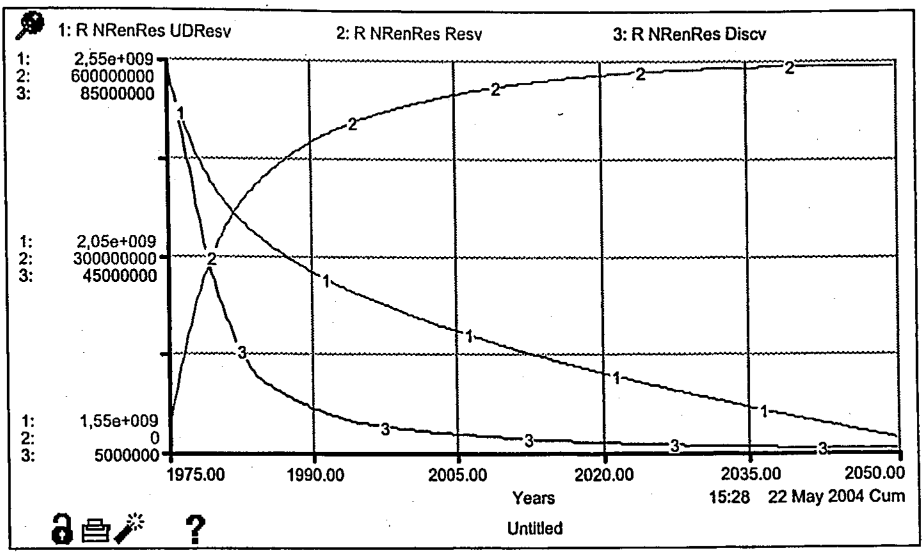


Figure 7.12. Non-renewable energy resource reserves behavior for the 1st case in extreme value tests

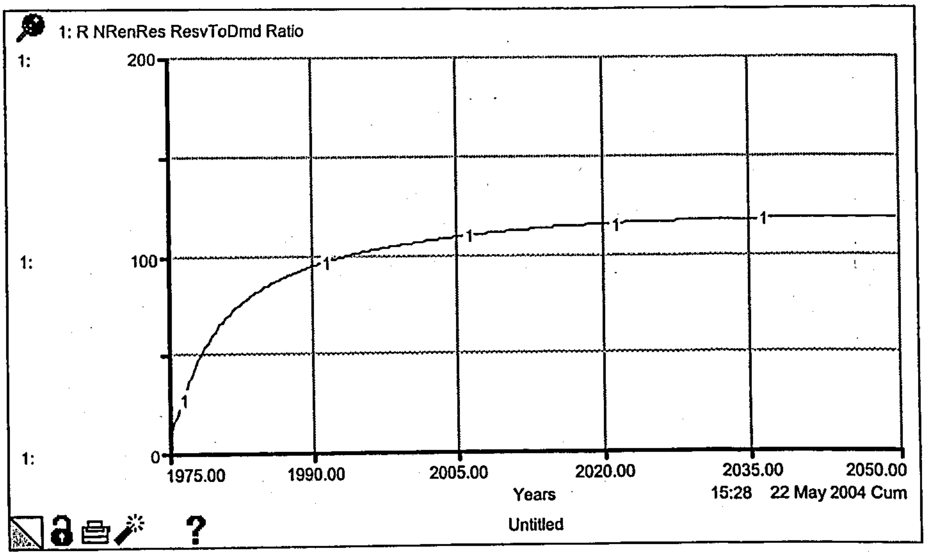


Figure 7.13. Reserve-demand ratio graph for the 1st case in extreme value tests

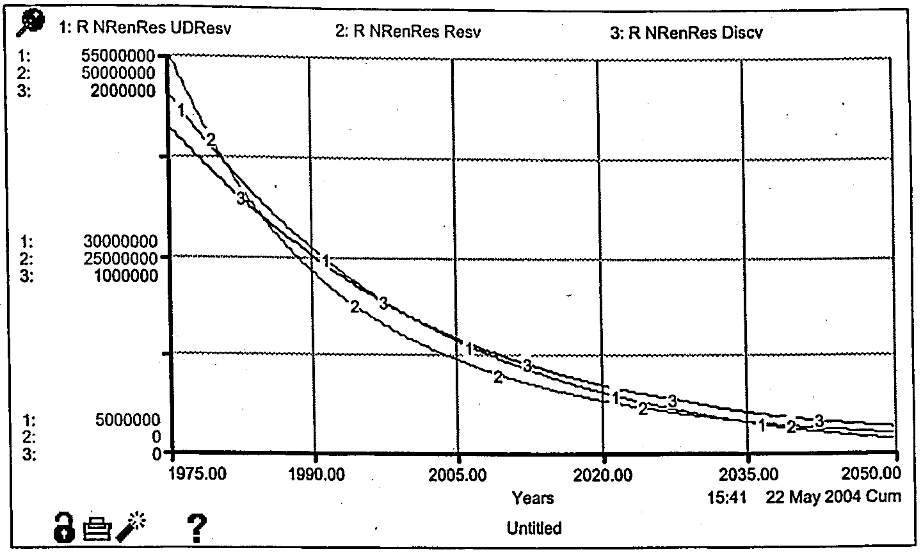


Figure 7.14. Non-renewable energy resource reserves behavior for the 2nd case in extreme value tests

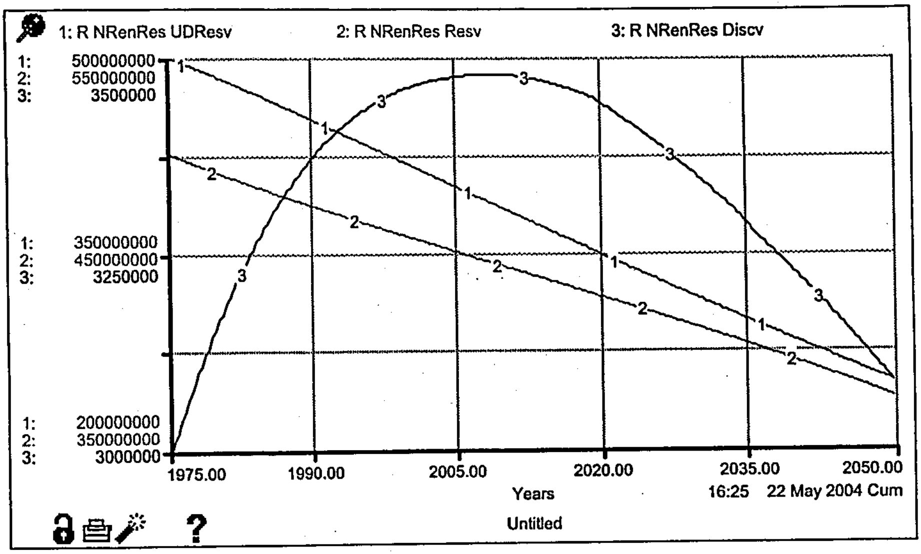


Figure 7.15. Non-renewable energy resource reserves behavior for the 3rd case in extreme value tests

In case 3, expected behavior is an inverse-U shaped discovery rate, which is dominated by the increasing exploration activity due to decreasing reserve-demand ratio during the first phase and by the decreasing undiscovered reserves in the latter decay phase. The model output in Figure 7.15 supports these expectations. The model output for case 4 is also identical with this case with respect to dynamic behavior. Only the numeric values differ. This is also consistent with expectations (see Figure 7.16).

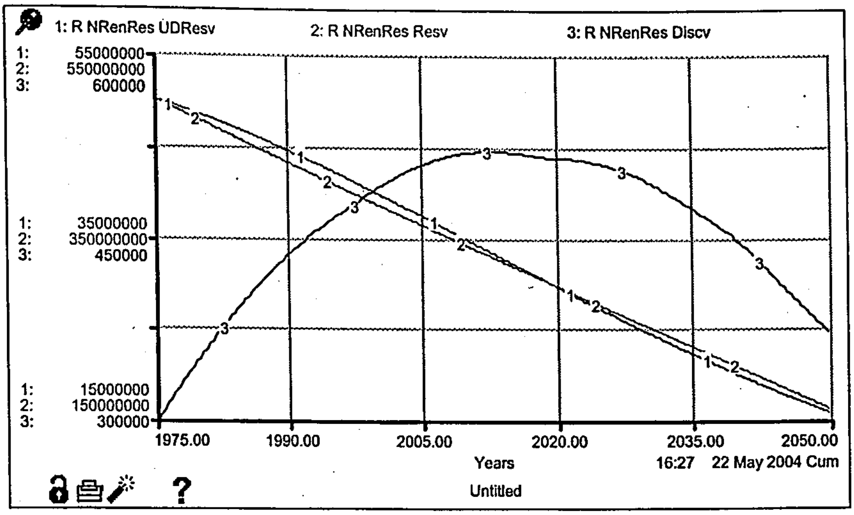


Figure 7.16. Non-renewable energy resource reserves behavior for the 4th case in extreme value tests

Based on the model behaviors observed in extreme value simulation tests and sensitivity analysis, the structure used in energy resources sector group is evaluated to be logically valid.

7.1.3. Economic Activity Sector Group Validity Testing

The model structure is tested for the reasonability of its behavior related to production specialization of the blocks. For this purpose, the output-capital ratio of North is defined to be very low in low technology segment, compared to high technology segment. On the other hand, South is set to have just the opposite situation. In such a setting, North is expected to specialize in high technology, whereas South is expected to specialize in low technology goods segments. In order to test this, an instantaneous increase in global low technology goods is introduced, and the behavior in Figure 7.17 is observed. South, having the greatest marginal return in shifting to low technology segment, demonstrates a rapid shift as a response to global shortage. Reaction of North, having a minimal marginal return in such a shift, can be considered as mild compared to the shift of South. Additionally, a contrary case is also tested, where an instantaneous global surplus is introduced. In such a setting, North demonstrated a significant shift out of low technology segment as expected (see Figure 7.18).

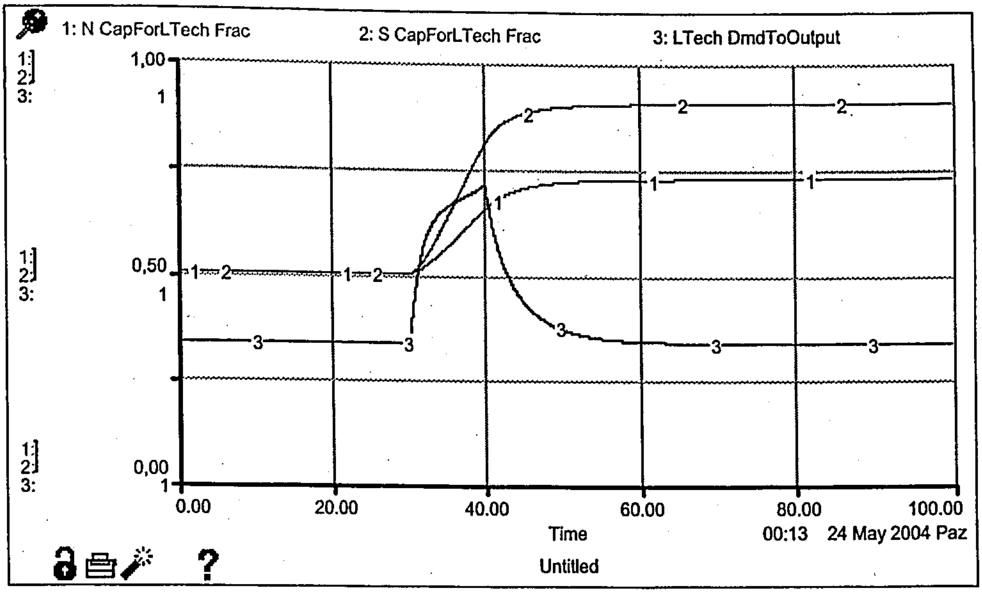


Figure 7.17. Capital shift observed in country blocks as a response to a global shortage in low technology goods

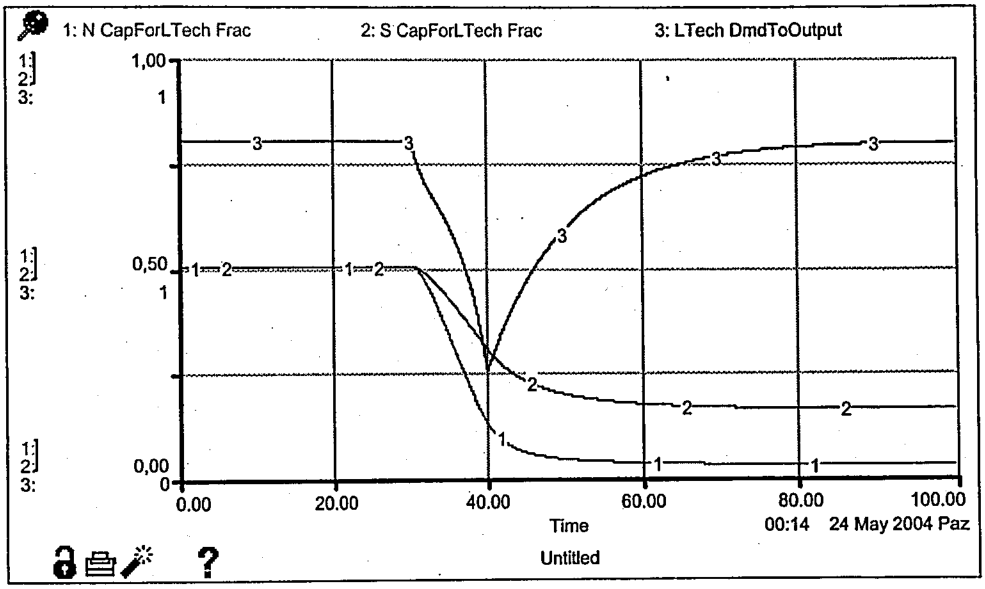


Figure 7.18. Capital shift observed in country blocks as a response to a global surplus in low technology goods

Additional to the expected differences in the reactions of country blocks to global imbalances, in these two cases the equilibrium seeking characteristic of the structure is also tested. In both of the cases presented in Figure 7.17 and Figure 7.18, global equilibrium in the supply and demand for a specific good type is restored as a result of the capital shift experienced in both country blocks. This can be observed by tracing the demand-to-output ratio (*LTech_DmdToOutput*) presented in both graphs.

The output-capital ratio is defined to be function of labor per capital ratio. The output-capital ratios generated by the model are tested with constant capital and extreme labor force values. In the first instance, both output-capital and output-to-labor ratios are studied by increasing the labor from initial level of 300 to 3000 million people. As expected an increase in output-capital ratio, coupling the decrease in output-to-labor ratio is observed (see Figure 7.19). Also, marginal increase in the output-capital ratio decreases as labor availability increases.

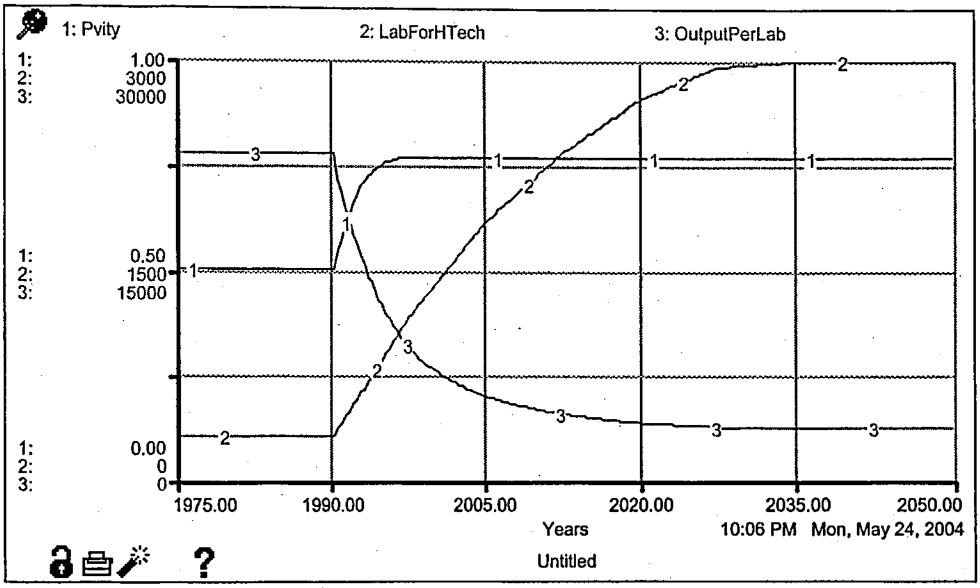


Figure 7.19. Change in output-capital (*Pvity*) and output-to-labor (*OutputPerLab*) ratios with constant capital and increasing labor

A similar test is also conducted with decreasing the labor from an initial level of 30 million to zero level. Behavior in both output-capital and output-to-labor are consistent with the expectations. The special case that deserves further attention is the output-capital ratio when labor equals to zero. In such a situation, no output is expected as production without labor is meaningless and illogical. As seen in Figure 7.20, this is guaranteed by the endogenous dynamics of the model by setting the output-capital ratio to zero, when labor equals zero.

Finally, the sensitivity of the capital accumulation to average capita lifetime variable is studied. Behavior of the stock variable representing capital is studied under four average capital lifetime values in the 10-50 years range. In all these four runs, behavior of the capital stock is observed to be insensitive to capital lifetime value in the 10-50 years range (see Figure 7.21).

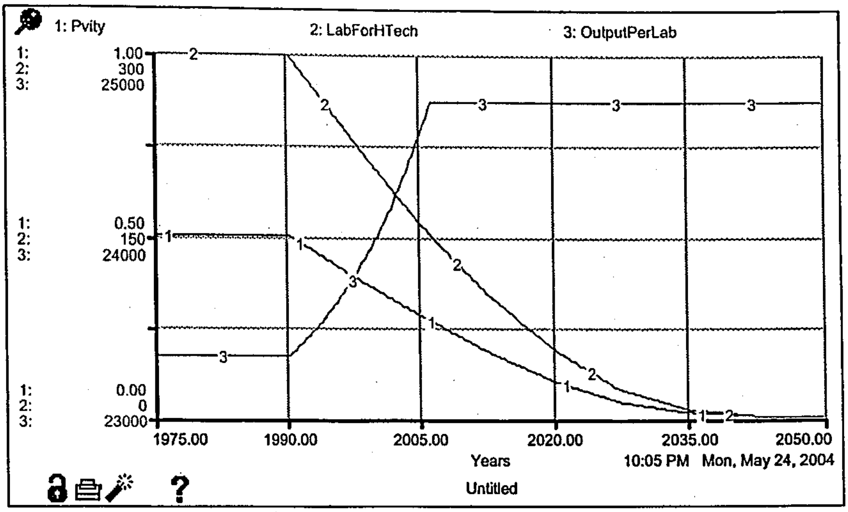


Figure 7.20. Change in output-capital (*Pvity*) and output-to-labor (*OutputPerLab*) ratios with constant capital and decreasing labor

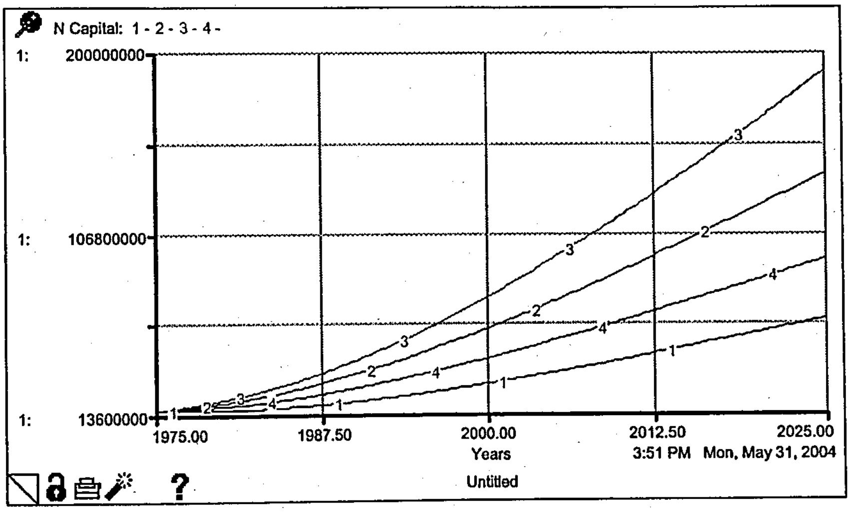


Figure 7.21. Capital stock behavior with average capital lifetime values of 10, 15, 25 and 50 years.

7.1.4. Pollution Sector Validity Testing

Behavior of the pollution sector is tested under extreme emission conditions. When a constant total global emission rate of 0 GtC/year is used, decay in atmospheric stock coupled with an inverted-U shaped behavior in oceanic stock is observed (see Figure 7.22). As there is no inflow to the atmospheric stocks, decay behavior due to oceanic uptake is consistent with the expectations. On the other hand, oceanic stock increases first due to the dominant inflow generated by the concentration difference between ocean and atmosphere. As this difference decays, dominance shifts to the outflow of the oceanic stock and stock level starts to decrease. Behavior is consistent with the assumptions regarding the carbon cycle theory.

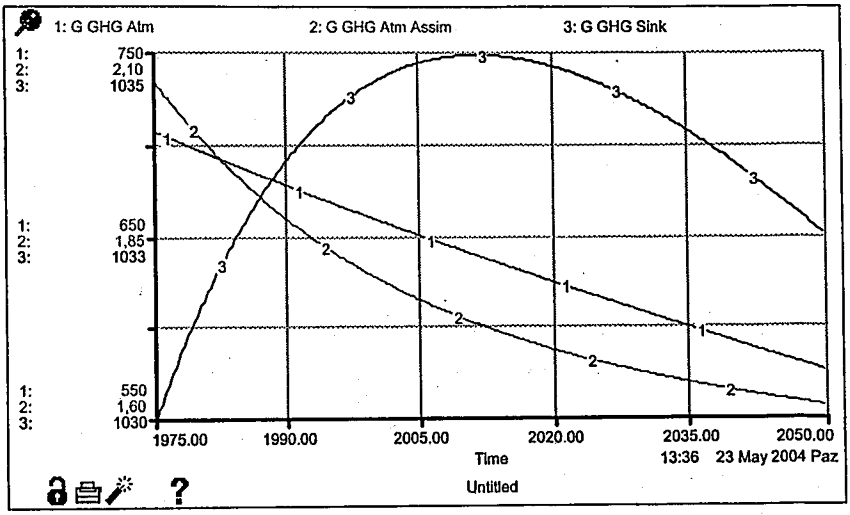


Figure 7.22. Behavior of CO_2 accumulation in atmospheric and oceanic sinks with constant global emission rate of 0 GtC/year

In order to test the system behavior under high global emission rates, a constant emission rate of 30 GtC/year is used, which is equal to 5 times the rate at year 1975 and 3 times the rate at year 2000. Such an extreme value is expected to initiate increasing atmospheric levels coupled with an increase in ocean-atmosphere concentration difference. Following that, a loss in the ocean uptake capacity is expected due to increasing oceanic CO_2 level. The model generates the behaviors in Figure 7.23 for both sinks and the flow between them. Increasing phase of the CO_2 assimilation from atmosphere

(*GHG_Atm_Assim*) is followed by a decreasing phase mainly due to the decreasing buffer capacity of the oceanic sink. In order to verify this reasoning, factors determining this rate are also studied. As seen in Figure 7.24, the concentration difference between two sinks (*GHG_AtmSink_ConcDisc*) increases throughout the simulation, and fraction of the concentration difference assimilated starts to decrease after a certain point. It is evident that this decrease is dominant in determining the behavior observed in CO_2 flow to the oceanic sink. This supports the validity of the structure with respect to the expectations based on the related theory depicted in IPCC reports (IPCC, 2001).

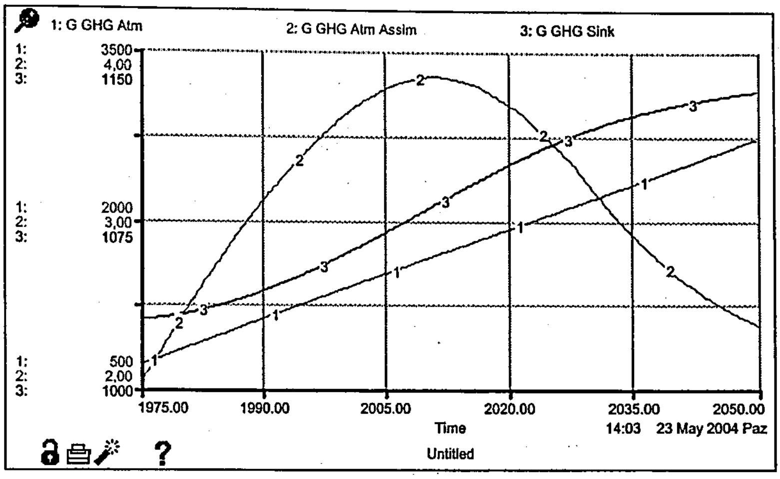


Figure 7.23. Behavior of CO_2 accumulation in atmospheric and oceanic sinks with constant emission rate of 30 GtC/year

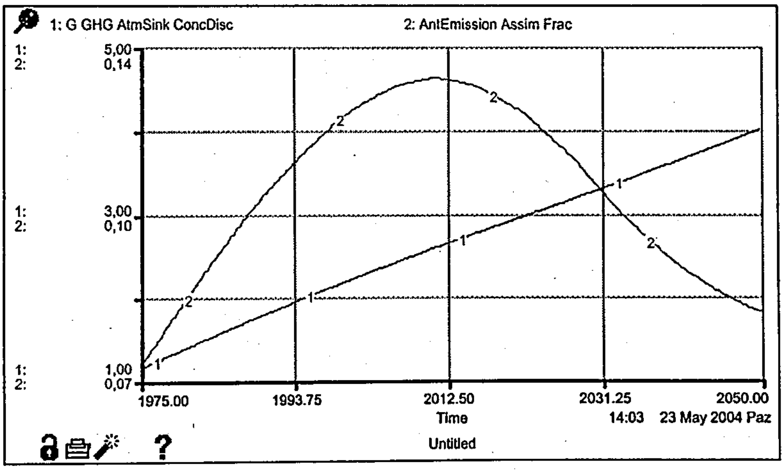


Figure 7.24. Concentration difference between CO_2 sinks with constant emission rate of 30 GtC/year

7.2. Behavioral Validation of the Model

In this section, behavior generated in the base run of the complete model is compared with available real data in order to improve confidence in the model. It is important to note that comparisons are made for the period between years 1975 and 2000, and the main focus is on the degree of fit in dynamic behavior pattern rather than precision in point predictions, which is impossible with ex-ante modeling. Although the degree-of-fit between the characteristics of dynamic patterns (slopes of trends, periods of oscillations, levels of steady states, etc.) observed in model output and real data is the main point considered in this stage, some statistics are also calculated to see the point-by-point fit produced by the model output. Results are summarized under subsequent sections.

7.2.1. Population Growth

The population figures generated by the model are compared with the time series data reported by World Bank (World Bank, 2003). The behavioral fit between the observed past data and the model generated data are quite satisfactory for both country blocks. The graphs comparing the real and model generated populations for North and South are given in Figure 7.25 and Figure 7.26, respectively.

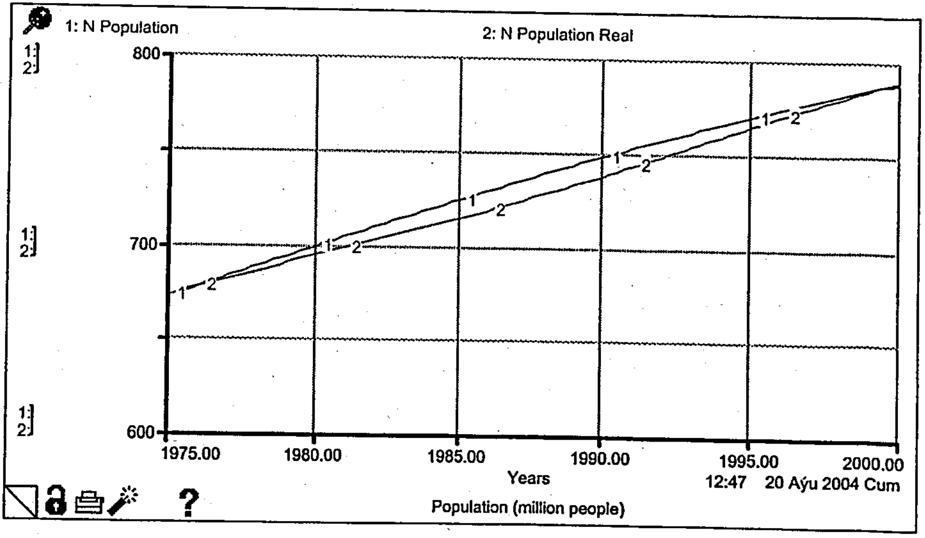


Figure 7.25. Real data vs. model generated population for North

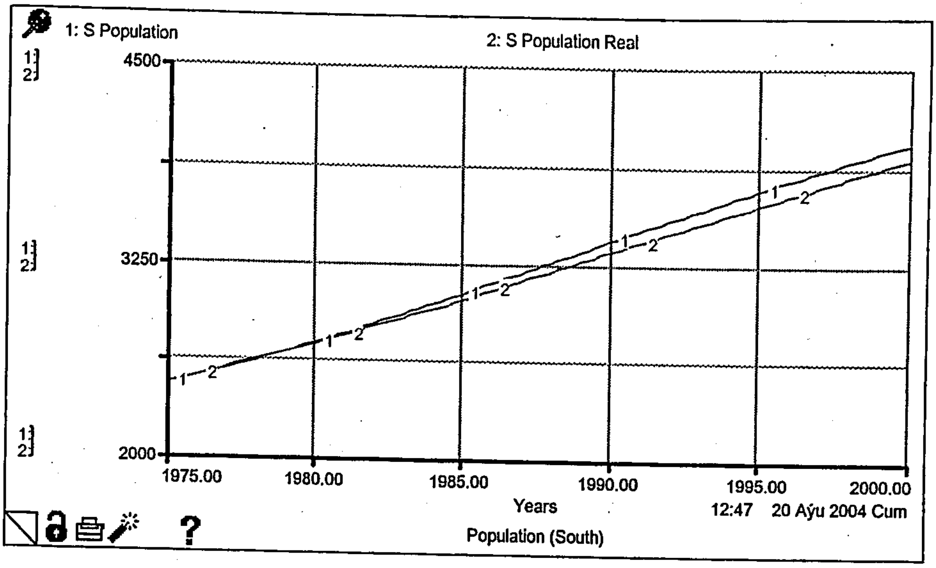


Figure 7.26. Real data vs. model generated population for South

In order to evaluate the point-by-point fit between the real data and model output coefficient of determination (R^2) and coefficient of correlation (r) are used. Refer to Equation (7.1) for the formulations of R^2 and r statistics (Montgomery and Runger, 1994; Sterman, 2000).

$$R^2 = r^2 \; ; \; r = \frac{1}{n}\sum \frac{(X_d - \bar{X}_d)}{s_d}\frac{(X_m - \bar{X}_m)}{s_m} \quad \text{where;}$$

$$\bar{X} = \frac{1}{n}\sum X \; ; \; s = \sqrt{\frac{1}{n}\sum (X - \bar{X})} \qquad (7.1)$$

X_m : Model output

X_d : Real data

Calculations are performed over the 26 data points, representing each year in the 1975-2000 period for both North and South. Using the formulation given above, R^2 values for North population and South population data are both found to be 0.99. These quite high statistics reveal that the model performs well in providing good numeric predictive accuracy, as well as similar dynamic pattern with real data series.

Apart from this analysis related to numeric precision of the model, some further analyses are conducted in order to evaluate whether the characteristics of the dynamic patterns of these data series are similar. During the regression analyses conducted for this purpose, it is observed that both real data and model output for North demonstrate a linear pattern, and linear regression model given in Equation (7.2) is applied. α and β values obtained with this test for real data and model output are summarized in Table 7.2. As seen in Table 7.2, α and β values calculated for these two data series are very close, so it is concluded that the dynamic characteristics of the model generated North populations are also satisfactory.

$$y_i = \alpha + \beta . x_i + \varepsilon_i \tag{7.2}$$

Table 7.2. Regression analysis for real data and model generated North population with linear regression model

	Real Data (1)	**Model Generated Data (2)**	**Per cent Error |(1)-(2)|/(1)**
α	664.83	664.03	0.12
β	4.7	5.191	10.45

Similar to North case, regression analysis is conducted to see the proximity of dynamic characteristics of real data and model output for South. Linear regression model provided the best fit to both real data and model output. Results of this analysis are presented in Table 7.3. As a result of these analyses, model is evaluated to perform well in providing good numeric precision and similar dynamic pattern compared to real data.

Table 7.3. Regression analysis for real data and model generated South population with linear regression model

	Real Data (1)	**Model Generated Data (2)**	**Per cent Error |(1)-(2)|/(1)**
α	2393.6	2391.7	0.08
β	56.835	58.442	2.83

Although the degree of fit between real and model generated population figures are quite satisfactory, several other demographic variables are studied in order to see if the model generates the right behavior for right reasons. Real values of these variables are taken from *World Development Indicators Report* of World Bank (World Bank, 2003). One of those variables is the number of births given per year. The comparisons of model generated and the real number of births are presented in Figure 7.27 for North and in Figure 7.28 for South. Although a slight numeric gap prevails for the figures belonging to North, the overall behavior is satisfactory. On the other hand, both numeric and behavioral precision of the model is very successful for generating births data for South.

Finally, urbanization pattern generated by the model is compared with actual trends. Model output is also successful in this aspect of demographic dynamics. Model generates a stabilizing urban population fraction around 80 per cent level for the North and an increasing urbanization without any slowdown for the South. These two patterns compared with real data are demonstrated in Figure 7.29 and Figure 7.30.

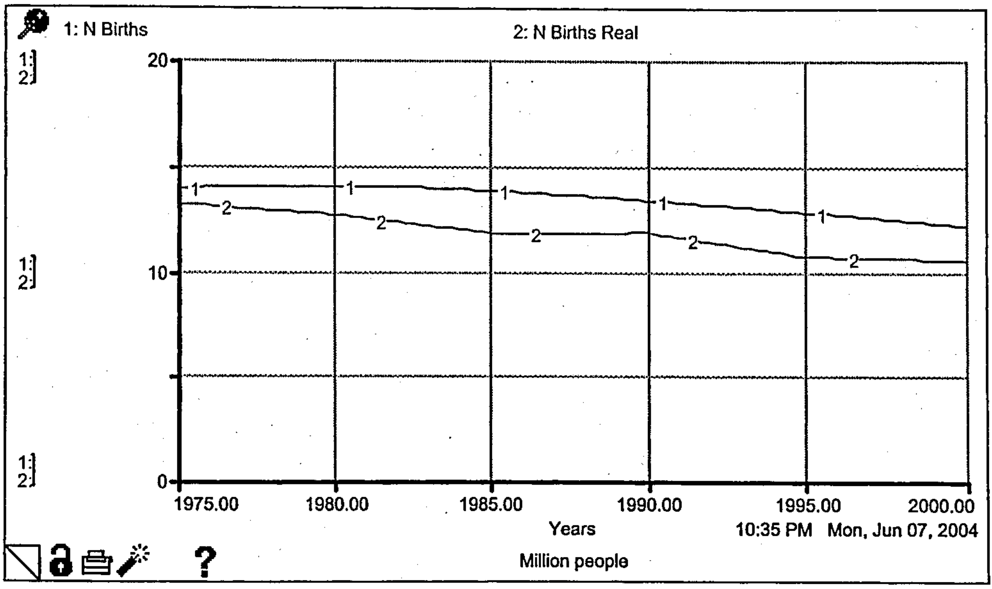


Figure 7.27. Real vs. model generated births per year for North

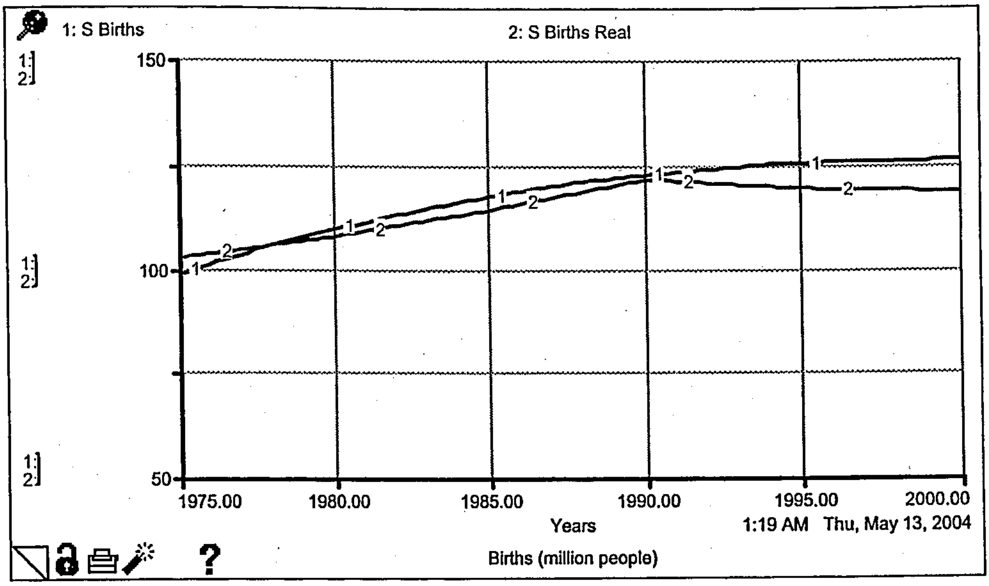


Figure 7.28. Real vs. model generated births per year for South

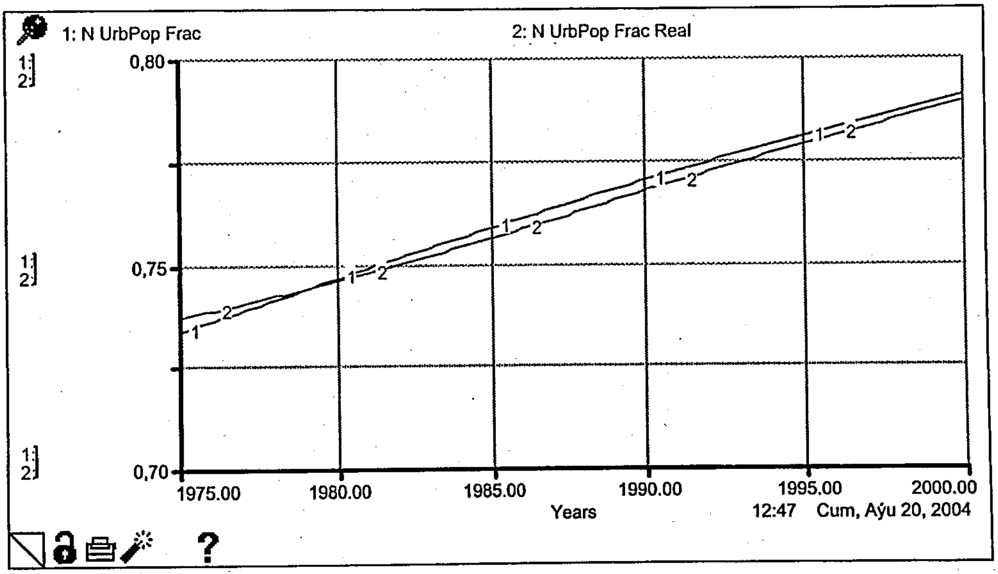


Figure 7.29. Real vs. model generated urban population fraction for North

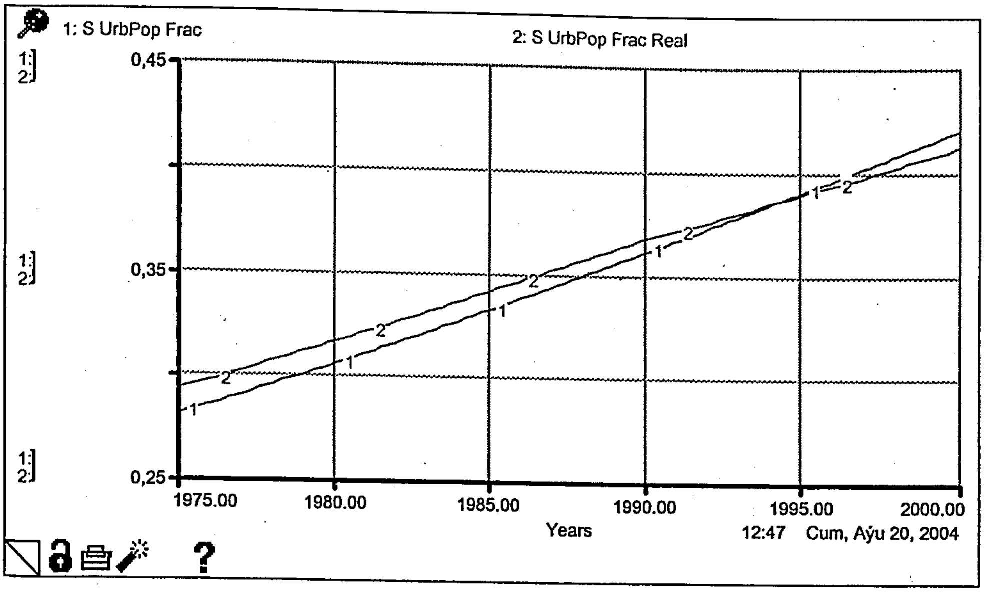


Figure 7.30. Real vs. model generated urban population fraction for South

7.2.2. Economic Output

As mentioned before, GDP in current international dollars is used as the indicator for the aggregated amount of economic output. In order to test the behavioral validity of the model, the model-generated economic output figures are compared with the GDP data from *International Comparison Programme* database of World Bank. The high degree of fit between the model generated and real data for North is evident in Figure 7.31. For South, exponential behavior observed in model output is supported by the real data, as seen in Figure 7.32.

Additional to the visual inspection, R^2 statistic (see Equation (7.1)) is calculated in order to check the goodness of fit between real data and the model output. For both North and South related data, this statistics is calculated to be equal to 0.99. These values reveal that model performs well in representing the real data related to economic output. As in the population case, dynamic characteristics of economic output series are compared. For North's economic output data, a linear regression model is used for this analysis. On the other hand, an exponential model is employed for the South's economic output data. Results obtained from these regression analyses are summarized in Table 7.4, and Table

7.5. These results supported the conclusion from visual inspection regarding proximity of dynamic characteristics of model output and real data.

$$y_i = \alpha . e^{\beta . x_i} + \varepsilon_i \qquad (7.3)$$

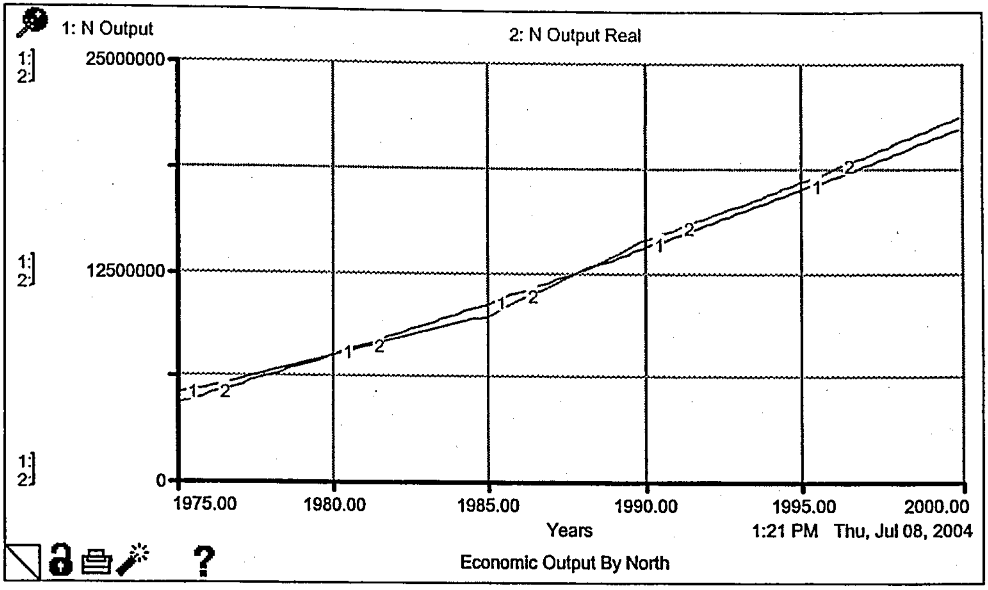


Figure 7.31. Real vs. model generated economic output for North

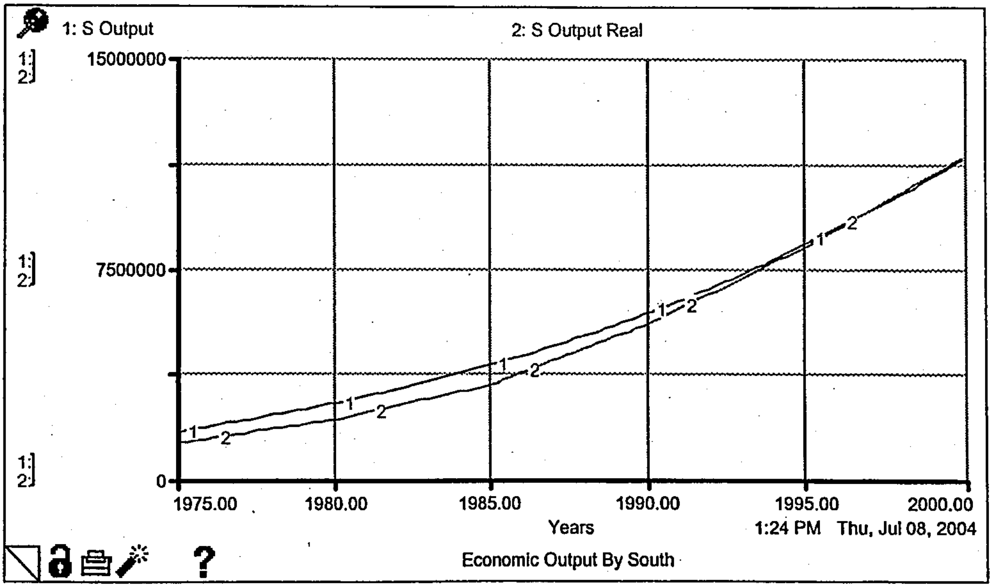


Figure 7.32. Real vs. model generated economic output for South

Table 7.4. Regression analysis for real data and model generated North economic output with linear regression model

	Real Data (1)	Model Generated Data (2)	Per cent Error |(1)-(2)|/(1)
α	3675930.56	4293028.26	16.78
β	702153.00	653924.35	6.86

Table 7.5. Regression analysis for real and model generated South economic output with exponential regression model

	Real Data (1)	Model Generated Data (2)	Per cent Error |(1)-(2)|/(1)
α	1303684.315	1766840.921	20.18
β	0.091	0.077	15.38

It is worth noting once more that main purpose in behavioral validity testing is to build a confidence in the degree of fit between the behavior modes of real and model data. Hence it is satisfactory to conclude that two data series demonstrate the same behavioral pattern (exponential growth for example) and have close values for the characteristic parameters of that behavior pattern.

7.2.3. Energy Consumption

Comparative graphs regarding the non-renewable energy resource usage of the blocks are given in Figure 7.33 and Figure 7.34. In the first graph, it is seen that the model is quite satisfactory in imitating the overall pattern of the resource usage at North. In Figure 7.34, it is seen that model captures the overall resource usage behavior for South block.

Concluding that the model performs well regarding the general pattern characteristics of North and South non-renewable energy consumption, R^2 statistics are calculated for North and South. For the North's consumption case, R^2 statistic is calculated to be 0.86. On the other hand, model performs much better in imitating the South case, with a R^2

value of 0.99. Relatively lower R^2 value in the North case is attributed to the remarkable shift in non-renewable energy consumption between the years 1980 and 1985. As a conclusion, both R^2 levels are evaluated to be satisfactory.

In the regression analysis a linear model is used for North and, β values of the two data are evaluated to be sufficiently close (see Table 7.6). For the South case, an exponential regression model provided the best fit. β values of real data series and model output are calculated to be equal to 0.558 and 0.572, respectively. Based on the observed deviation that is less than 3 per cent, model output for South energy consumption is evaluated to be satisfactory.

Table 7.6. Regression analysis for real and model generated North energy resources consumption with linear regression model

	Real Data (1)	**Model Generated Data (2)**	**Per cent Error |(1)-(2)|/(1)**
α	29702445	26522896	10.70
β	16563	14972	9.60

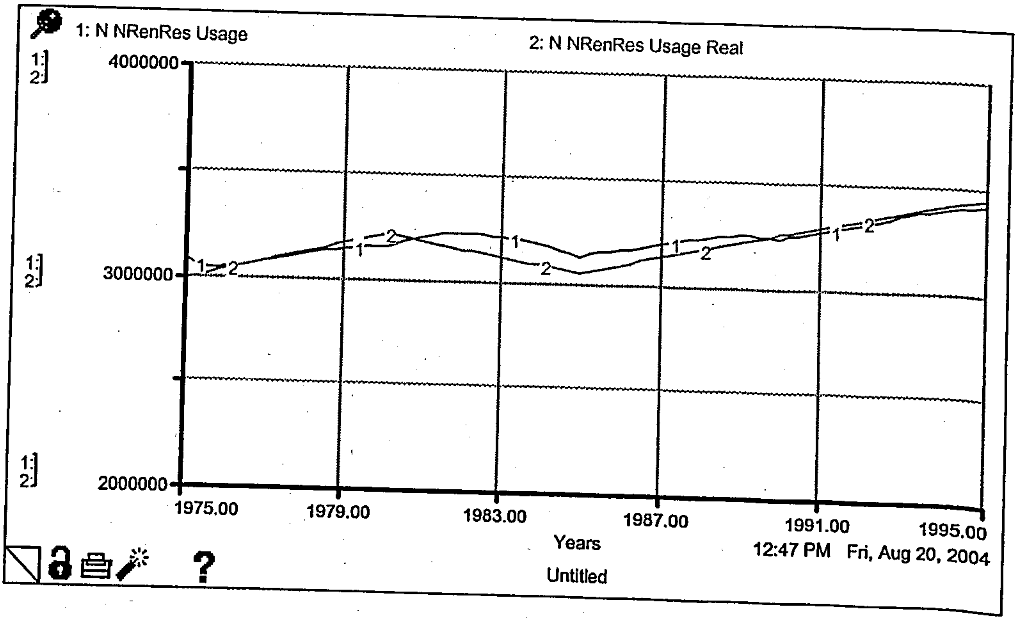


Figure 7.33. Real vs. model generated non-renewable resource usage by North

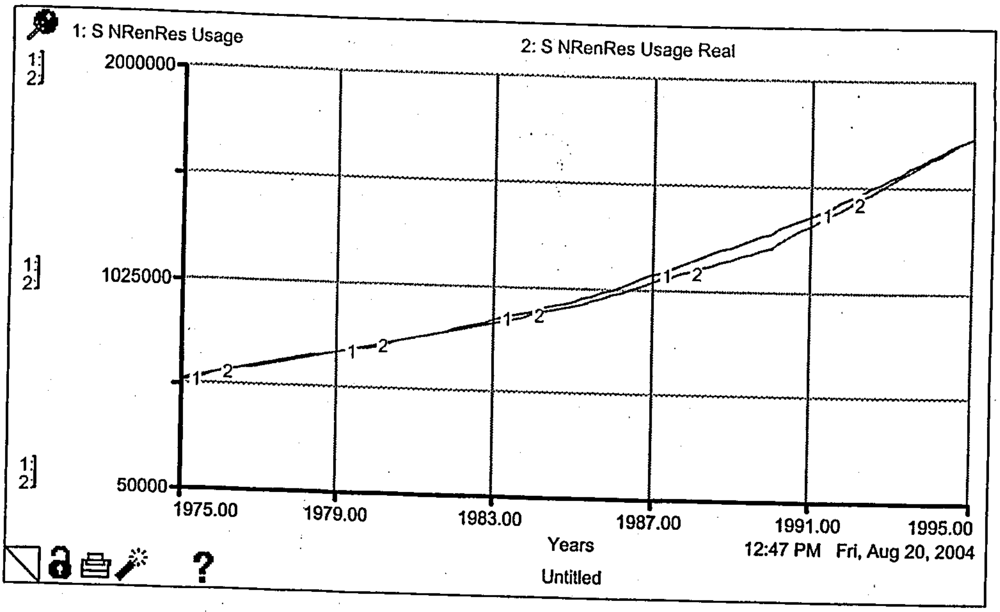


Figure 7.34. Real vs. model generated non-renewable resource usage by South

7.2.4. Carbon dioxide (CO_2) Emissions

Model generated carbon dioxide (CO_2) emissions are compared with real data for North and South. Despite slight numeric discrepancies, the behavior of CO_2 emissions caused by North seems to demonstrate a good fit to the behavior observed in real emissions (see Figure 7.35). On the other hand, the model also captures the long-term trend in the CO_2 emissions caused by South with a good precision (see Figure 7.36). R^2 value for the model output and real data related to North originated emissions are calculated to be equal to 0.88. On the other hand, same statistic is found to be equal to 0.99 for the South case.

Also, model generated estimations for the RoW originated emissions seem to be very successful (see Figure 7.37). As mentioned before, RoW originated emission are estimated by using resource usage and carbon intensity values calculated as a weighted average of corresponding variables at North and South.

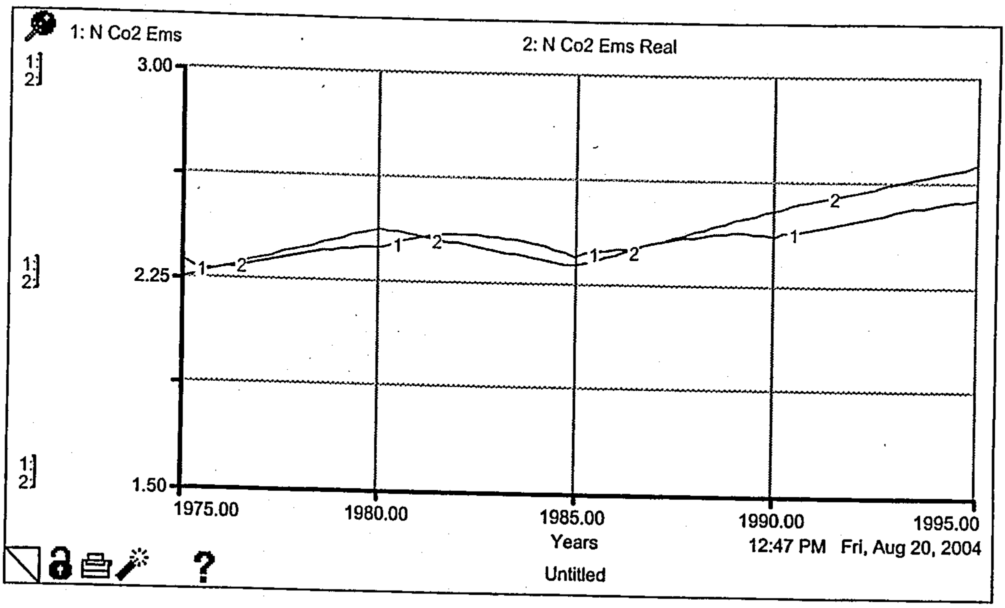


Figure 7.35. Real vs. model generated CO_2 emissions from North

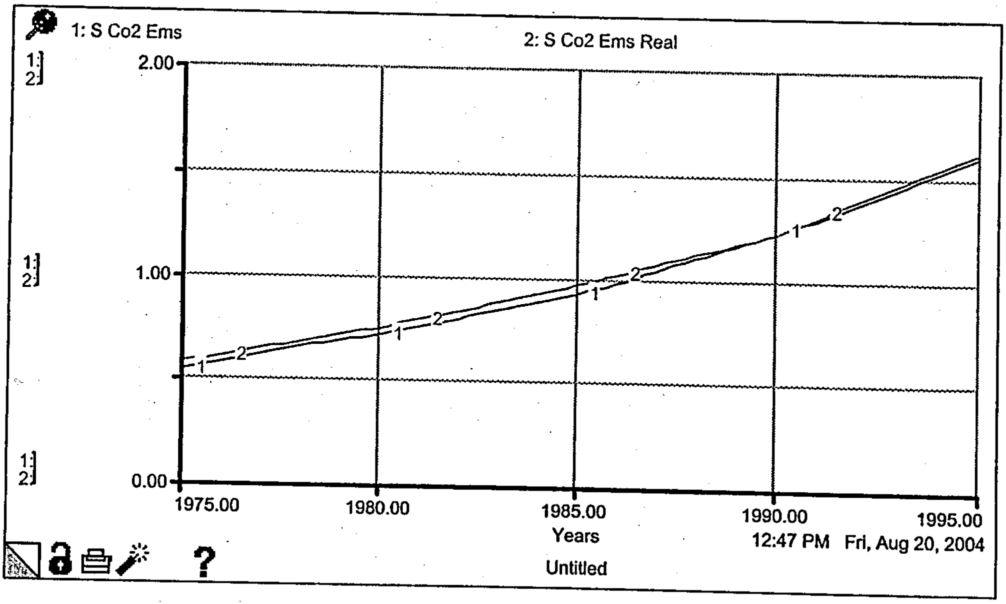


Figure 7.36. Real vs. model generated CO_2 emissions from South

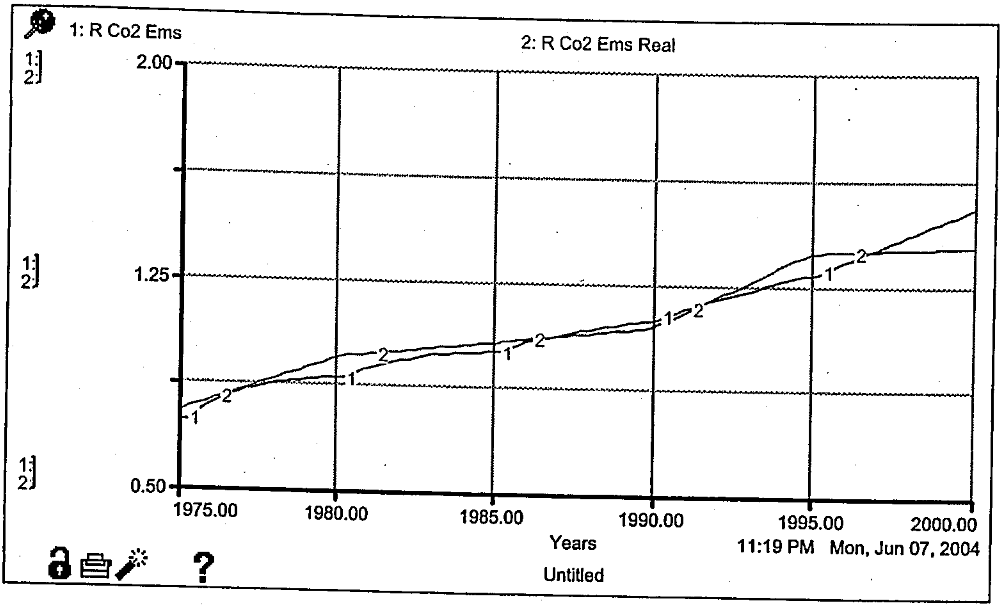


Figure 7.37. Real vs. model generated CO_2 emissions from RoW

Finally, the model generated atmospheric CO_2 concentration caused by these CO_2 emissions are plotted in Figure 7.38 against the measured CO_2 level in the atmosphere. For the 25-year period covered in this comparison both numeric precision and the behavioral fit of the model generated figures are quite satisfactory (R^2 equal to 0.99).

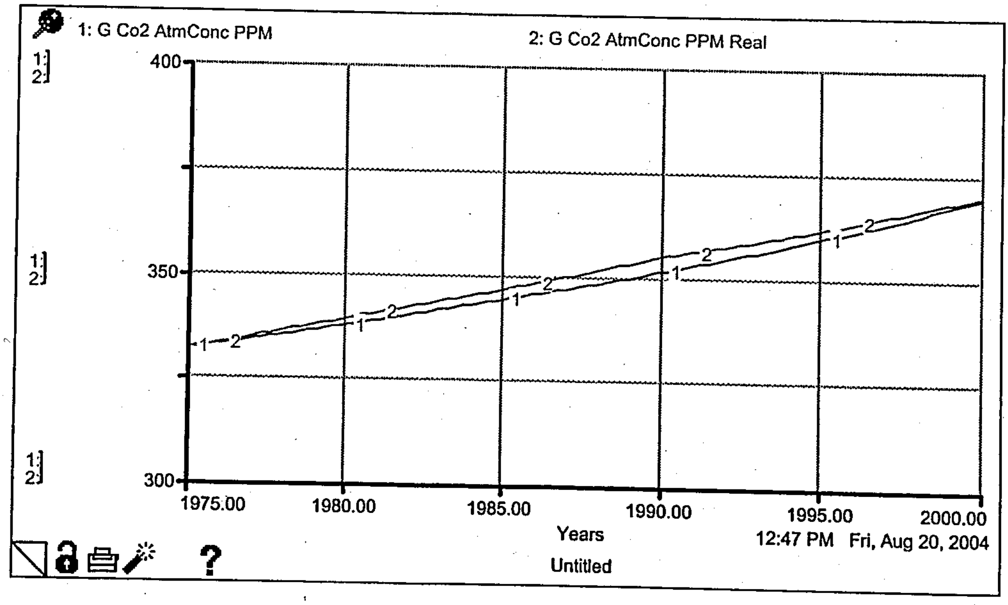


Figure 7.38. Real vs. model generated atmospheric CO_2 concentrations (ppm)

8. BASE BEHAVIOR AND PROJECTIONS OF THE MODEL

In this section, the model output obtained in the base run is demonstrated. It should be considered that the base run of the model completely depends on the initial values of variables and assumptions documented in Chapter 6. Reference behavior of the model with respect to major variables is demonstrated. Major variables are grouped under the headings of economic output, population, energy consumption and pollution.

8.1. Population

As expected, an increasing global population that reaches the level of eight billion is observed in the base run. When the sources of this increase are studied, it is clearly evident that the behavior of the global population is dominated by the increase in South. Populations of both North and RoW blocks seem to stabilize at some point in the first quarter of 21st century. However, the population growth in South continues with a decreasing rate throughout the first 50 years of the century (see Figure 8.1). These results obtained regarding the global population are consistent with the mean variant projections of United Nations, which estimates a global population around 8.9 million at the middle of the century. Also, findings are parallel to the foresight of Barney in estimating that virtually all the increase in the global population will be South originated (Barney *et al.*, 1991).

In Figure 8.2 and Figure 8.3, the behavior of the age groups in North and South is presented. As expected, North continues to get older during the 75-year time horizon of the run. In the detailed plot of North population in Figure 8.2, it is seen that the total population starts to decline after the first quarter of the century. This behavior is also consistent with the projections in the *World Population Prospects: The 2002 Revision*, in which a probable population decrease is estimated to start in developed nations around 2030.

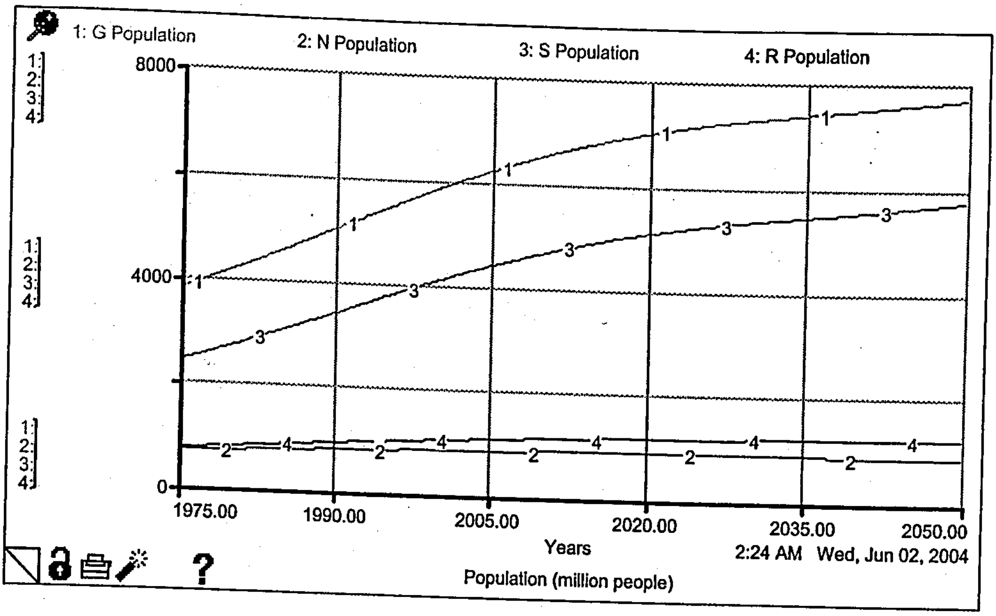


Figure 8.1. Population dynamics in the base run

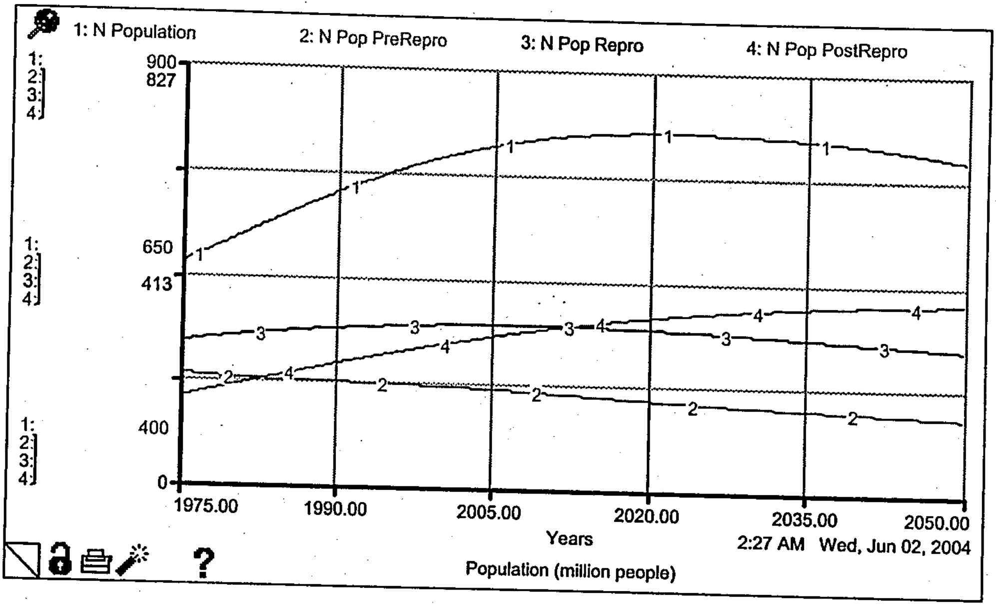


Figure 8.2. Dynamics of total population and age groups for North

Observed behavior in the South population is given in Figure 8.3. Growth rate of the total population starts to decrease and finally gets close to stabilization around 2050. Meanwhile, South population is also observed to be getting older, which is an important factor in terms of population growth rate.

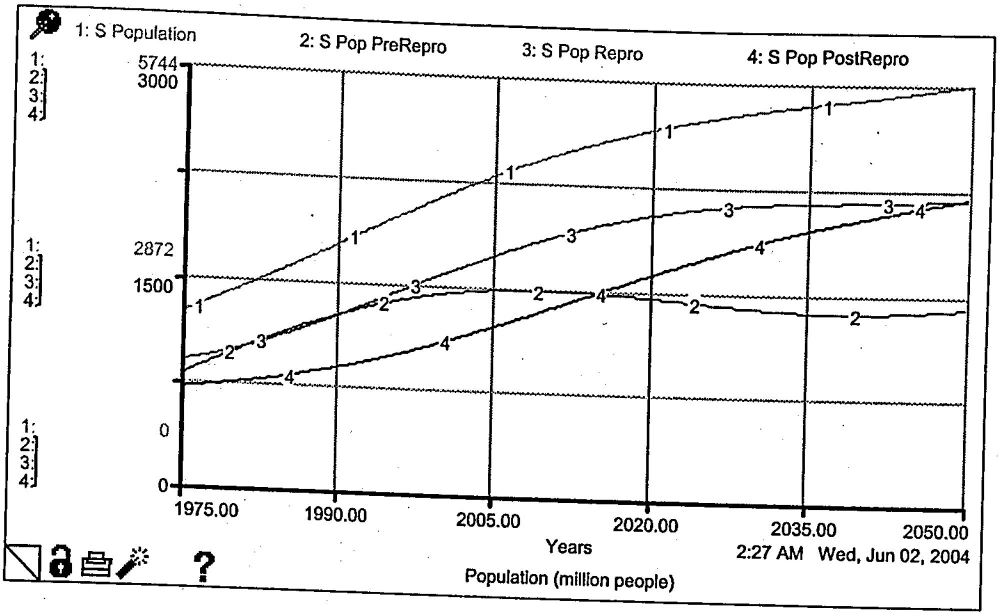


Figure 8.3. Dynamics of total population and age groups for South

As the South population plays a vital role in determining the global population level in the base run of the model, stabilization process of this population group is further investigated in detail. When the underlying reasons of the dynamic pattern observed in the South population are studied, two competing mechanisms are identified. First is the decreasing death fraction for all three age groups due to increasing life expectancy in South. This mechanism alone is expected to result in an increasing population growth rate. However, a second mechanism working in the reverse direction dominates this first one in the long term and is mainly responsible for the stabilization of the overall South population. According to this mechanism, increased per capita output and decreasing infant mortality rates cause average desired fertility level to decrease after a delay. In turn, decreased average desired fertility level results in a reduction in the total number of births, which is the single inflow of the overall South population. Relative strengths of these two mechanisms can be clearly seen in Figure 8.4, which separately demonstrates the ratio of total number of deaths and births to the total population. As seen in the figure, reduction in the overall birth fraction is greater compared to the reduction in the overall death fraction. When the net rate of change in the total South population (total number of births less total number of deaths) is considered, it is seen that net rate of change is positive throughout the simulation horizon, but it consistently decreases in value. This decreasing positive net rate of change is responsible for the observed pattern of the total South population.

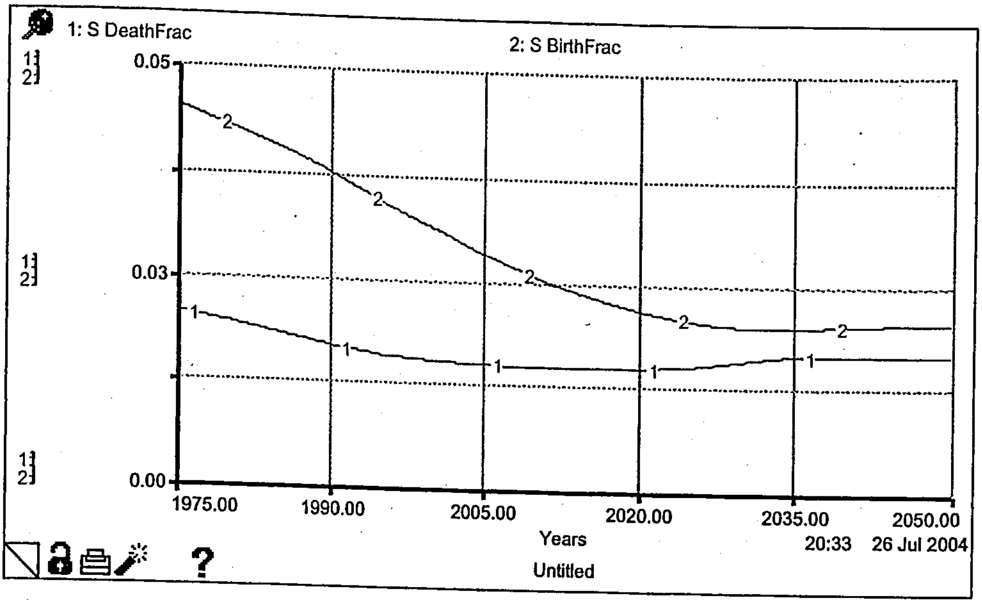


Figure 8.4. Fraction of deaths and births in total population of South

Additionally, dynamics observed in individual age groups of South population are also studied. Among the three age groups, two of them stabilize in the simulation time horizon (see Figure 8.3). Pre-reproductive age group stabilizes mainly due to decreasing (births) inflow to this age group. The stabilization of the pre-reproductive age group yields stabilization in the flow from pre-reproductive age group to reproductive age group. As this stabilized inflow to the reproductive age group balances with the net outflow of the age group, the reproductive age group of the South population also stabilizes around year 2030. The only growing age group of South populations, which is post-reproductive one, is expected to demonstrate a similar dynamic pattern in the long term and stabilize at some point beyond the time horizon of the base run

8.2. Economic Output

Gross output generated in the country blocks are observed to be as in Figure 8.5. In the first phase of the economic output behavior, an exponential growth trend is observed in both North and South, the latter having a higher growth rate. The second phase starting prior to 2030 is a recession period caused by shortage experienced in non-renewable energy resources (details regarding the resource shortage will be discussed in Section 8.3). Impact of the shortage seems to be different for two blocks. North seems to recover in about 10 years and recaptures economic growth, which is even faster than the growth experienced in the first phase. On the other hand, impact of the shortage seems to be more severe for South, as economic output fails to capture an upward trend during the 30-year period following the beginning of the shortage. In order to understand the causes underlying this difference in the economic output patterns, economic output related dynamics are further studied.

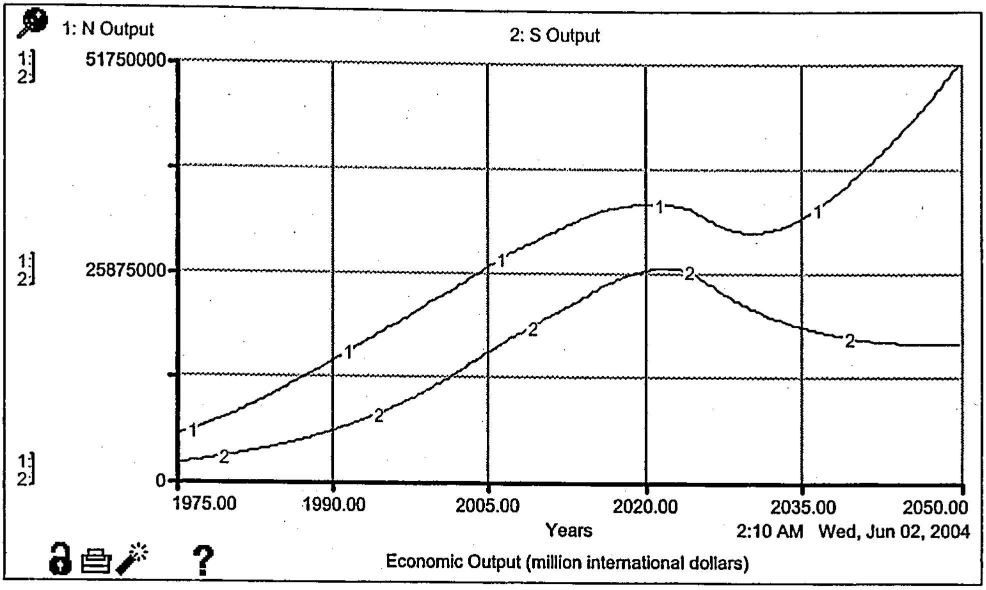


Figure 8.5. Economic outputs generated in North and South

As mentioned in model description sections, output generated by a block is constrained by two factors; capacity of the available production factors and the available energy capacity. When these two constraints are plotted on the same graph, Figure 8.6 is obtained for North. As it can be seen in the figure, energy capacity (line 2) is the factor that constrains the economic output and decrease in the capacity of energy resources is mainly responsible for the observed recession. However, the output capacity of the existing production factors (line 1) is considerably higher and continues to increase even during the recession period. So, the recession period can be described as a period of underutilization of the existing output capacity due to energy scarcity. As the alternative energy capacity is installed, an increase in the utilization of production factors is observed. In other words, the steep increase in the North's output after 2030 is mainly caused by increased utilization of preexisting production factors, not by an abnormal investment pattern or a technological breakthrough.

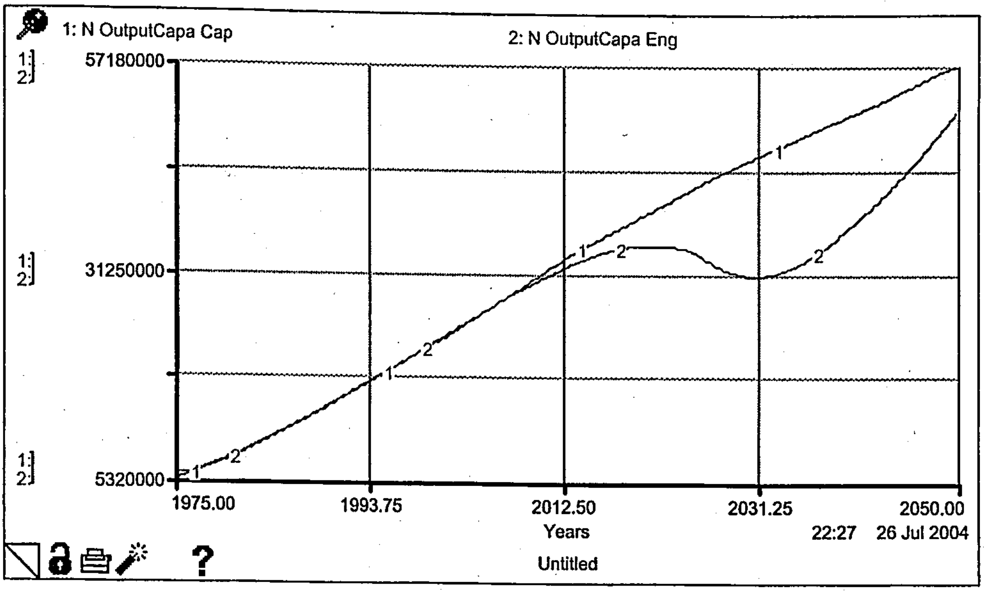


Figure 8.6. Output capacity of North with available production factors (Line 1) and energy resources (Line 2)

The picture for the South is very similar to the one described above. As it can be seen in Figure 8.7, South's recession is also due to decreased utilization of the production factors. It is evident that output capacity of these factors is far above the level that energy resources of South can support. There is no decrease observed in the output capacity of production factors, but rate of change of this variable (*S_OutputCapa_Cap*) severely stagnates for South, which is not the case for North. This stagnation is marked with an eclipse on Figure 8.7. Although the situation seems to be similar for both blocks up to this point, we fail to observe a fast recovery in economic output in South from this point on. This is mainly because of slower alternative energy capacity installation in South due to the late response and limited investment power of the block in the energy field. Hence, a recovery behavior in the South's economic output similar to the one experienced in North may only be expected beyond the time horizon of the base run. However, characteristics of this recovery may be a bit different. First of all, due to the slow energy capacity installation process, recovery behavior will probably be less steep. On the other hand, investment required for energy constitutes a remarkable portion of total investment capacity of South, which indicates less investment allocated for production capital. This yields a situation that is not observed in North. Investment to the physical capital falls below the experienced depreciation rate and this causes the stagnation observed in output capacity of physical capital (marked with the eclipse in Figure 8.7). As a result economic output capacity of production factors, which is determined by available labor, physical capital, and production technology, is severely damaged during this energy crisis.

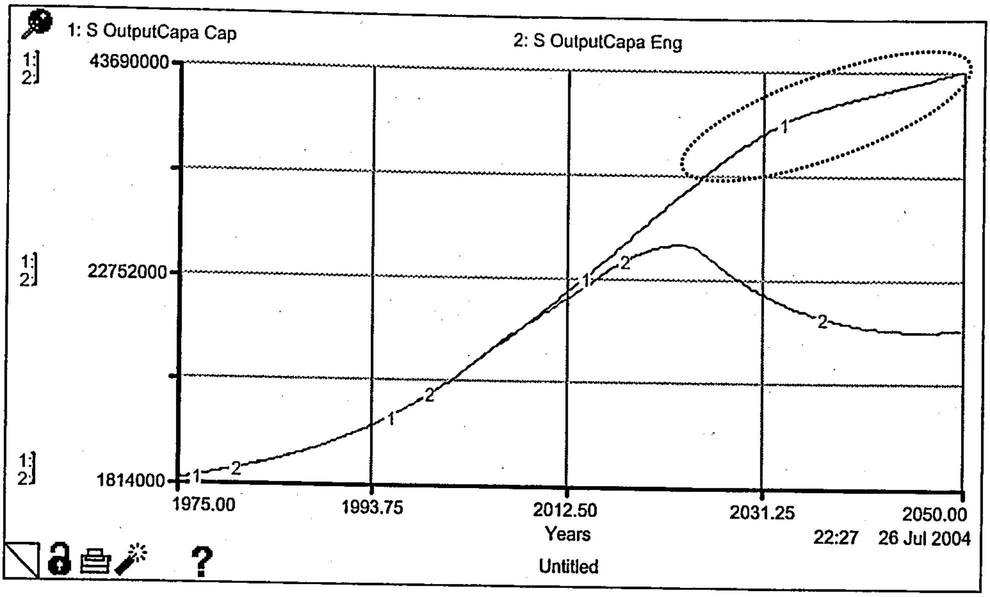


Figure 8.7. Output capacity of South with available production factors (Line 1) and energy resources (Line 2)

However, trends in the gross output do not reveal much information regarding the welfare and development level of the blocks. Conclusions on these issues can be made only by observing the per capita output levels. Behavior of output per capita for both North and South are presented in Figure 8.8.

In Figure 8.8, a continuously widening welfare gap is observed. Although South demonstrates a faster growth in gross output, population dynamics of this block prevents it from closing the gap in output per capita. A serious welfare loss is observed in South during the resource shortage period. As population continues to increase as gross output decreases, a dramatic decrease in output per capita is observed during this period. This situation is better observed in Figure 8.9. In this graph, output per capita levels are given in the indexed form. For each block, output per capita level of corresponding block in 1970 is used as the base in indexing. Additionally, the ratio of output per capita value of North to the value in South is also presented in the same plot. As it can be seen clearly, a slight decrease in relative ratio of output per capita is observed until 2020, which can be interpreted as a closing welfare gap. Following the shortage experienced in energy resources, this ratio climbs to a level that is almost four times of the 1970 level.

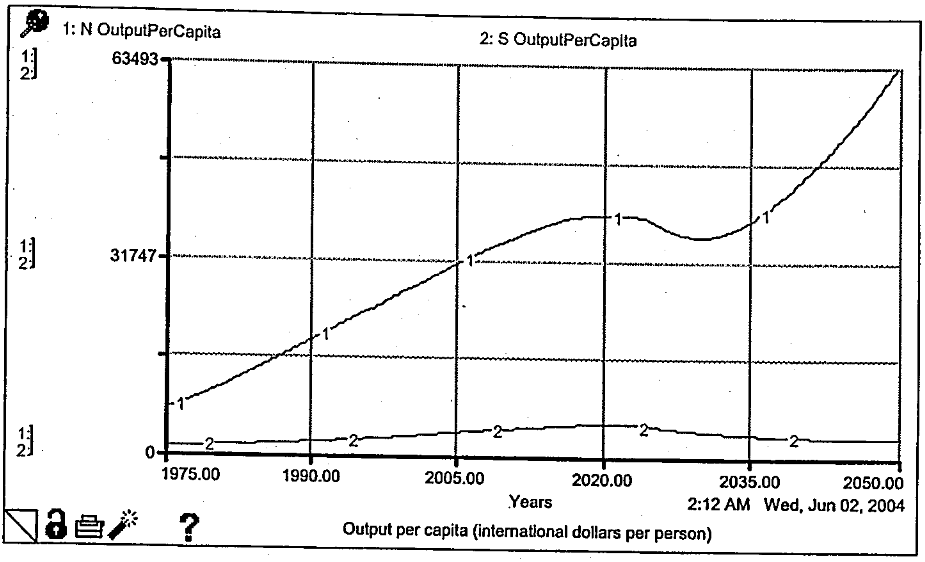


Figure 8.8. Behavior of output per capita in North and South

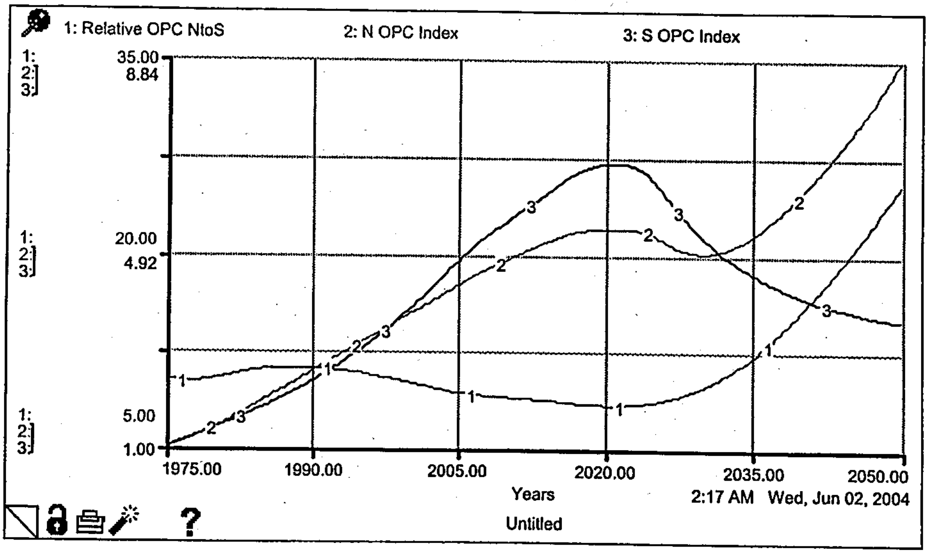


Figure 8.9. Indexed output per capita values for North and South (base year 1975)

8.3. Energy Resources Consumption

In Figure 8.10, the status of the non-renewable energy resource reserves are presented as well as the global production rate for these resources. Resource content of the discovered reserves increases until the year 2005 as a result of reserve discoveries offsetting and even exceeding the production rate from these reserves. While the discovery rate declines as a consequence of decreasing undiscovered reserves, production rate continues to increase. This, in turn, results in the initiation of the decrease experienced in discovered resource reserves. Meanwhile, the production rate from discovered reserves reaches its peak point around 2025 and starts to decline as a response to decreasing reserve availability. The behavior shift in the global resource production resembles the starting point of the shortage experienced in energy resources.

Behavior of discovered reserves and global production obtained from the base run seems to be consistent with the expectations of WEC, which estimates that fossil fuel production will reach its peak and start to decrease somewhere in the period between 2025-2050.

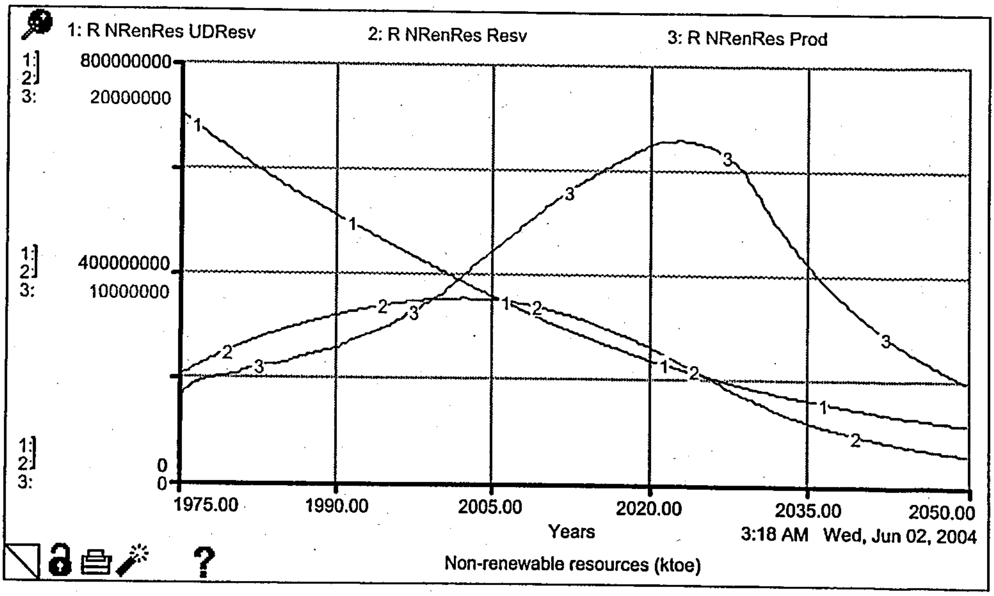


Figure 8.10. Non-renewable energy resources reserve levels and production rate

Behavior of the non-renewable resource usage observed for all three blocks are almost identical. As seen in Figure 8.11, they all reach their peak points between 2020 and 2030, and then start to decline. However, dominant factors in the decline period vary between North and South. As a response to declining resource reserves, North initiates the shift in energy resources from non-renewables to renewables and this shift speeds up after 2020. By 2050, it is observed that North generates more than 50 per cent of its energy demand from renewable resources (see Figure 8.12). This resource shift in energy supply seems to be the dominant factor in the declining non-renewable resource usage in North. On the other hand, South also initiates the shift in energy resources, but technological capabilities and investment power prevents South from experiencing a significant shift. By 2050, South seems to be dependent on non-renewable resources for almost 80 per cent of its energy demand. Based on this observation, decline in non-renewable usage in South is mainly due to decreased resource supply to the block, rather than decreased demand in the block. Finally, it is important to note that South emerges as the fastest growing non-renewable resource user and its share in global usage catches up the level of North in the second quarter of the 21st century.

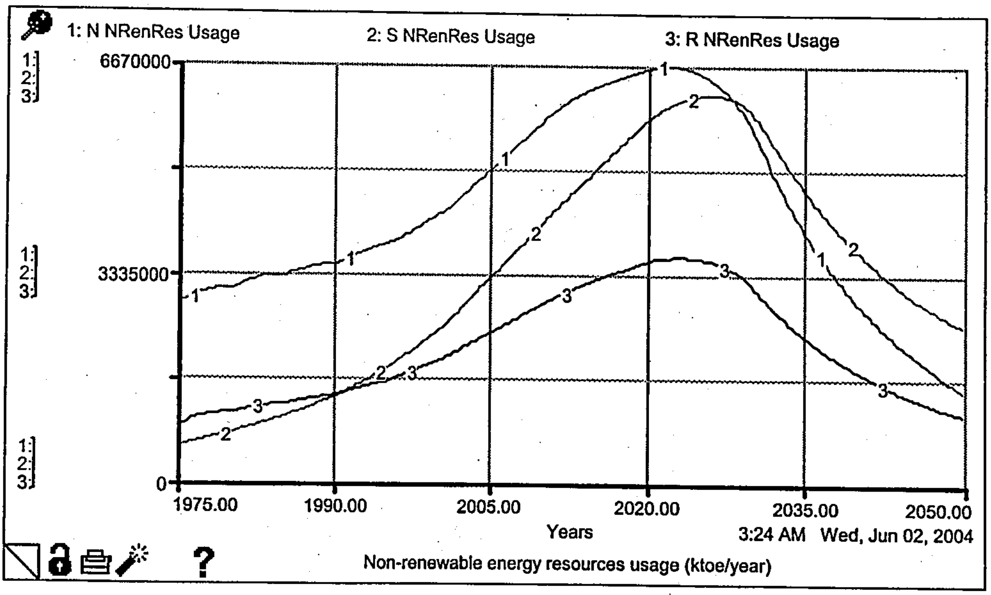


Figure 8.11. Non-renewable energy resources usage rate in all three blocks

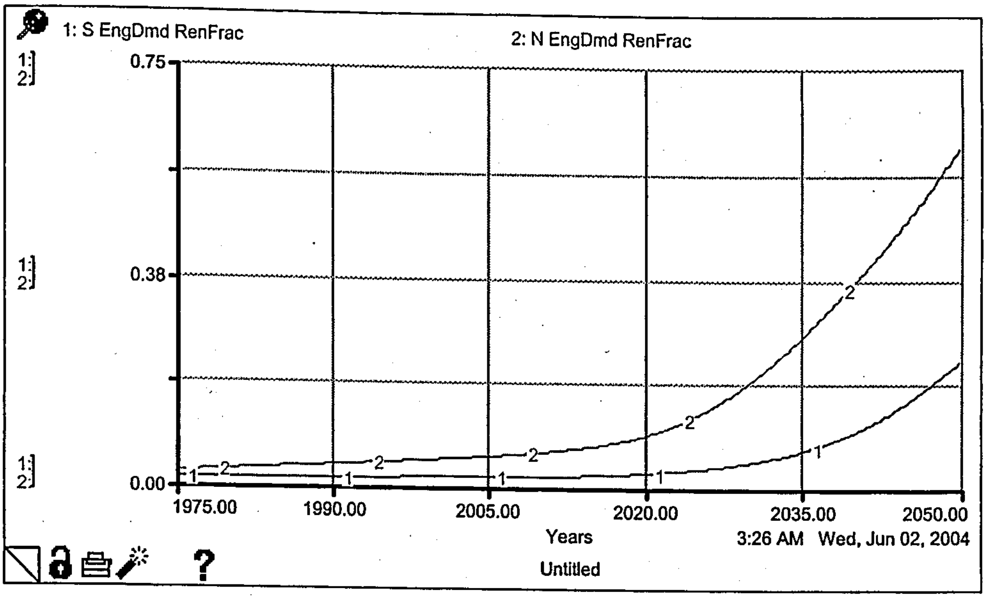


Figure 8.12. Fraction of renewable energy demand in North and South

In Figure 8.13 and Figure 8.14, output capacity of the available production capital is plotted against the maximum output that can be generated by the available energy capacity. For both blocks severe capital underutilization is observed, but it is evident that the impact of energy shortage is more significant at South.

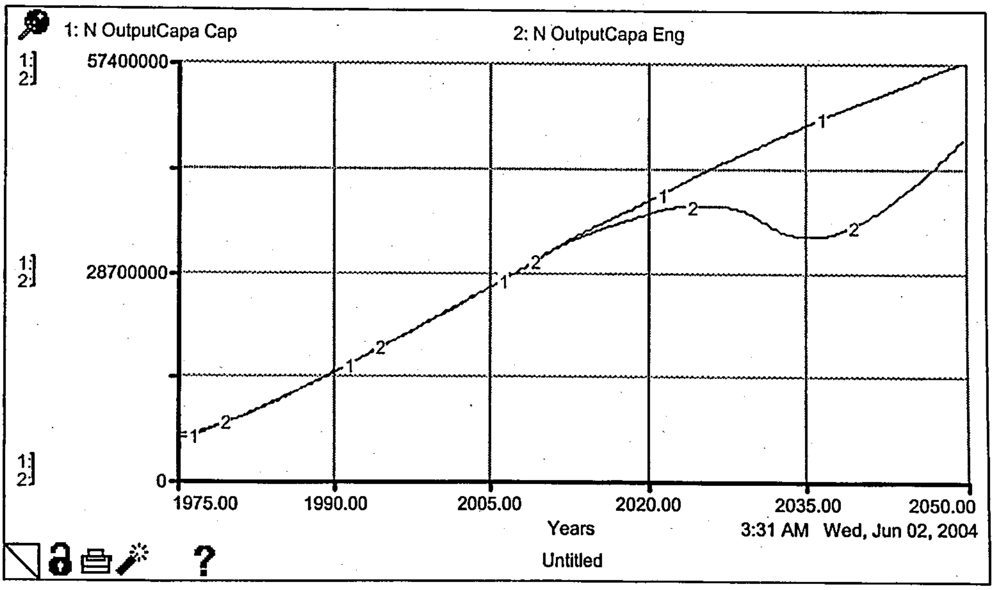


Figure 8.13. Capital vs. energy capacity for output generation in North

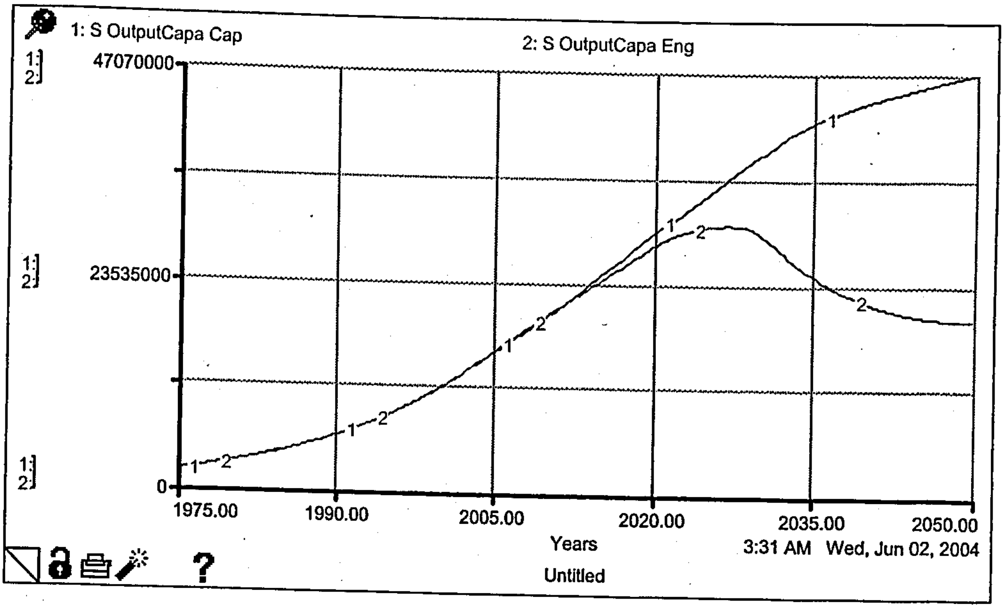


Figure 8.14. Capital vs. energy capacity for output generation in South

8.4. Global Pollution

As greenhouse gases are directly related to non-renewable resource usage, patterns observed in emissions are very similar to the ones observed for non-renewable resource usage (see Figure 8.11 and Figure 8.15). The point that deserves attention is the fast growth in South originated CO_2 emissions. After some point close to 2025, South takes the lead from North in CO_2 dumping to the atmosphere.

When the atmospheric CO_2 concentrations are studied with respect to those emission levels seen in Figure 8.15, an S-shaped pattern is observed in atmospheric concentrations. According to this pattern, steepest increase in atmospheric concentration is experienced between 2000 and 2020, the period during which South originated emissions increase considerably. Following this phase, a diminishing growth rate followed by stabilization is seen between 2020 and 2050. At the end, it is observed that atmospheric CO_2 concentration almost stabilizes around 530 ppm by volume.

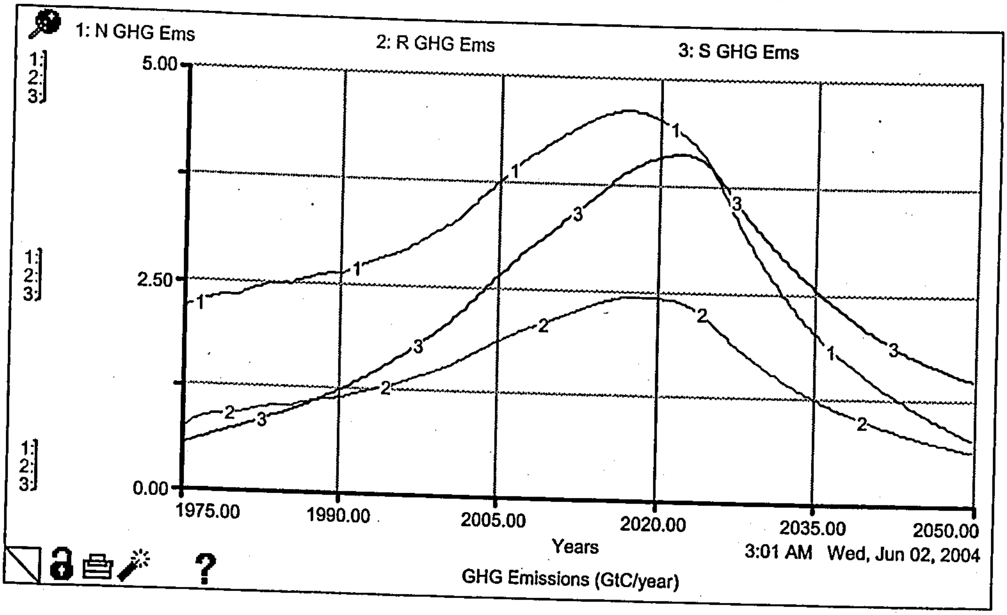


Figure 8.15. CO_2 emission rates for all three blocks

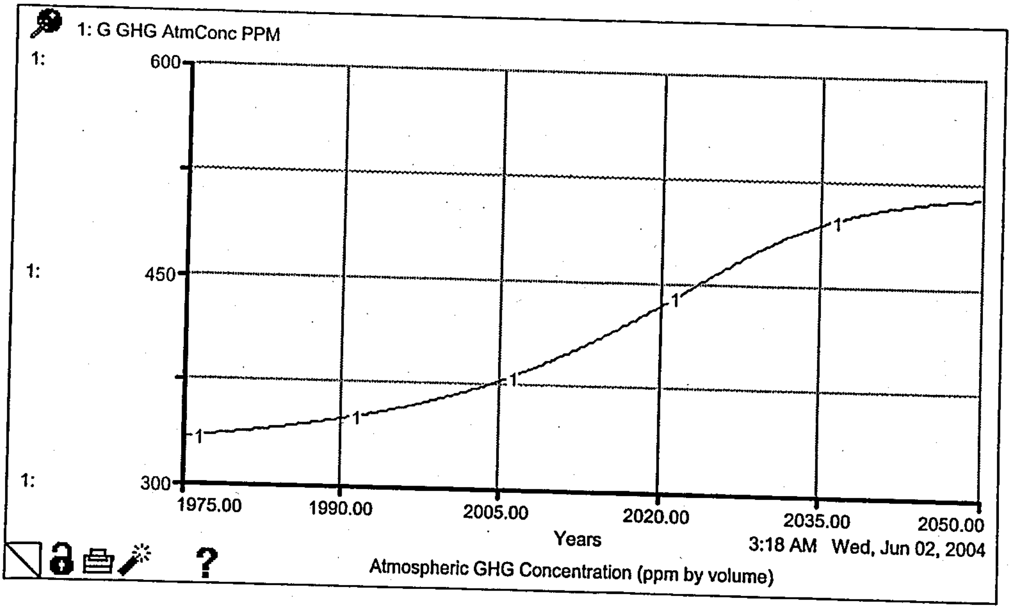


Figure 8.16. Atmospheric CO_2 concentration

9. SCENARIO ANALYSIS

In this section, various scenarios are studied by using the model described in the preceding chapters. Certain scenarios required modifications in the model structure and in the variable values used. These modifications are documented in the corresponding sections of each scenario. The variables that are directly related to the changing conditions according to the scenario are studied in detail, and the patterns observed for these variables are discussed. Unless unexpected and significantly changed behaviors are observed, variables other than these are not discussed.

9.1. Mild Fertility Decrease at South

A significant fertility decrease at South is one of the main expectations in many of the population projections. In this scenario, the case with only a mild decrease instead of a significant one is studied, in order to see the population growth pattern. This scenario is tested with two different settings with differing causes of the mild decrease in fertility levels. In the first case, problem is attributed to poor birth control experience, which prevents having exactly the desired number of children. So, instead of using an increasing fertility control effectiveness input to the model, a constant value of 70 per cent is employed. As seen in Figure 9.1, behavior of South population significantly changes, compared to the base behavior that can be seen in Figure 8.3. Instead of stabilizing around six billion people, South population reaches nine billion people level and more importantly no sign of slow down is observed in the growth pattern.

In the second case, the hypothesized relation between the desired number of children and per capita output level is manipulated. A slight change in this relation, which causes an increase by 1 in the fertility level on average, results in the population behavior presented in Figure 9.2. Differing from the former case, a diminishing growth rate is evident in the behavior of the South population. However, it is important to note that marginal contribution of this slight change in family size preferences is around two billion people added to the global population.

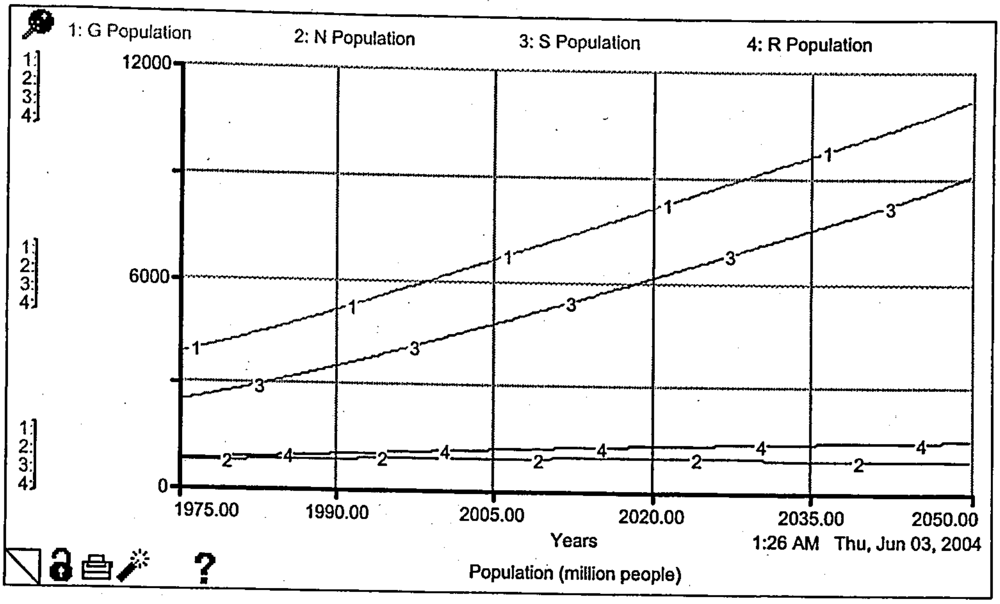


Figure 9.1. Behavior of global population with ineffective fertility control at South

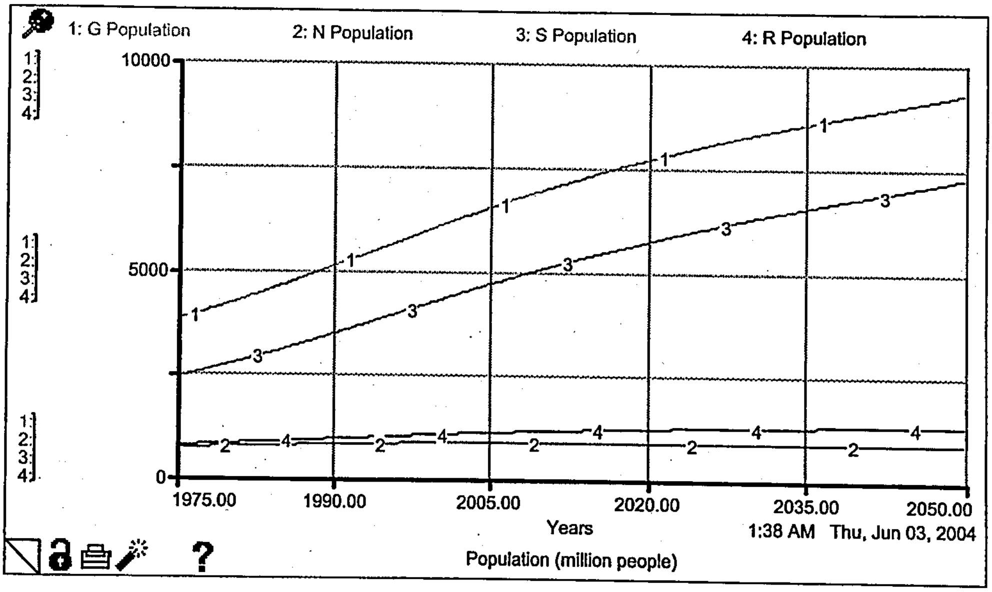


Figure 9.2. Behavior of global population with decreased responsiveness of family size to increased income

9.2. Decreasing Labor Participation Fraction in North

In the base run of the model, a constant labor participation fraction is used. However, considering the increasing age composition of North, it is viable to experience some degree of decrease in this fraction. So, labor participation fraction decreased gradually from 0.45 in year 2000 to 0.35 in year 2025.

No significant changes are observed in the patterns of global resource usage or pollution. However, an economic slowdown mainly due to decreased output-capital ratio is observed in North. As expected, decreasing labor force participation fraction caused a decrease in the total labor force, which is responsible for the decrease observed in output-capital ratio. Change in the economic output pattern of North is presented with the comparative plot in Figure 9.3, on which both economic output from the base run and this scenario can be seen.

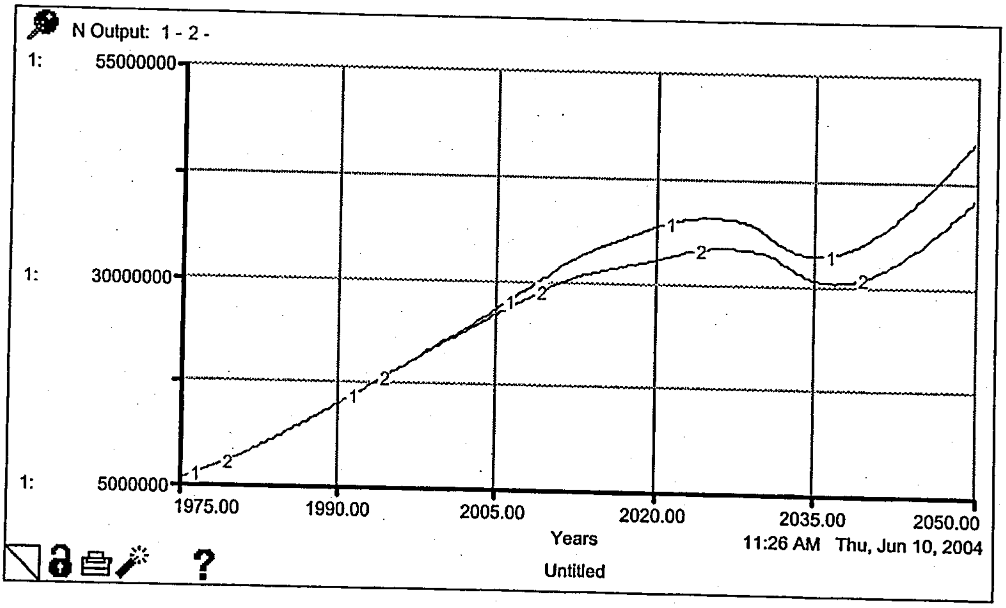


Figure 9.3. Economic output of North in "decreasing labor participation fraction in North" scenario

Apart from the expected change in the output pattern of North, a seemingly unrelated change is observed for South. Compared to the base run, a slight increase in the gross output is observed. Underlying fact seemed to be the reduced North based resource usage due to the slowdown depicted above. This change can be seen in Figure 9.4. This simple scenario reveals that long-term output of each block is clearly dependent on the past performance of the other.

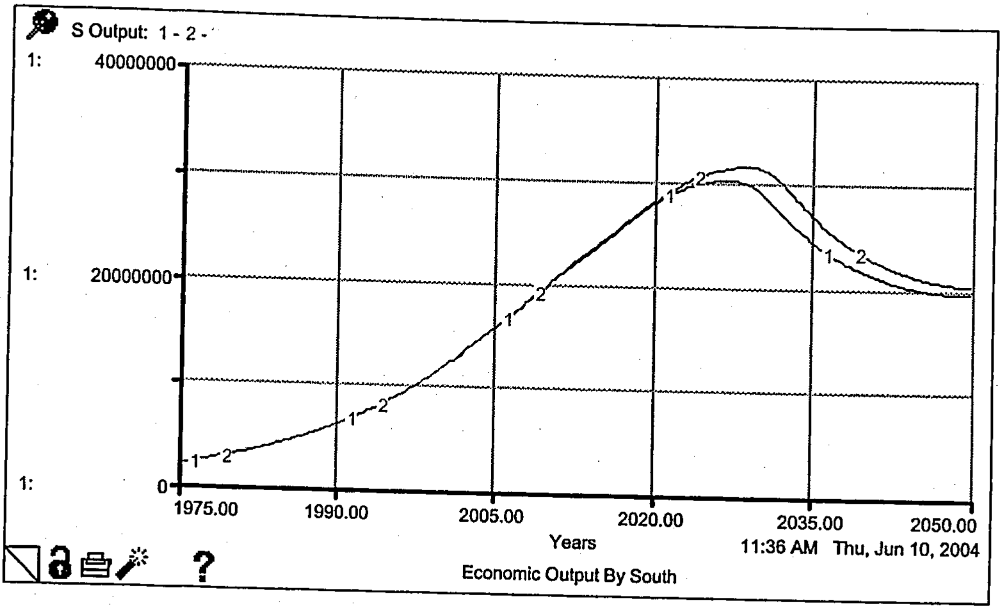


Figure 9.4. Economic output of South in "decreasing labor participation fraction in North" scenario

9.3. Changes in the Balance of Goods Exchanged in Favor of North

In this scenario, it is assumed that the terms of trade between North and South are distorted after year 2000 in favor of North. Although factors determining the terms of trade vary, international debt is assumed to be responsible for such a distortion, which is likely to occur in the following decades. As the aggregation level of the model prevents modeling the debt problem properly, it is assumed that due to increasing foreign currency deficit, goods received from North are decreased (representing the import reduction) by 20 per cent in year 2000 and balance is restored in 10 years.

According to the two-segment economic framework employed in the model, North specializes in high technology sector and emerges as the major supplier of such goods, supplying almost 75 per cent of high technology goods demand of South in the base run. Additionally, parallel to the development experienced in South, share of high technology goods increases in the investment composition. Hence, such a decrease in the goods received from North is expected to originate a reduction in the investment capabilities of South.

The effect of this reduction is clearly evident in Figure 9.5, in which investment growth is significantly interrupted as a consequence of limited high technology goods availability. Also exponential growth experienced in capital stock shifts to a linear growth pattern in the same period. Although growth patterns in both capital investment and capital stock are recaptured after the restoration of terms of trade, economic slowdown experienced in this period prevents South from attaining the per capita output growth rates observed in the base run. As seen in Figure 9.7, ratio of output per capita levels experienced in North and South sustains its initial value until the energy crisis and then increases significantly. However, in the base run, this ratio is observed to decrease as a consequence of rapid economic growth of South between 2000 and 2030.

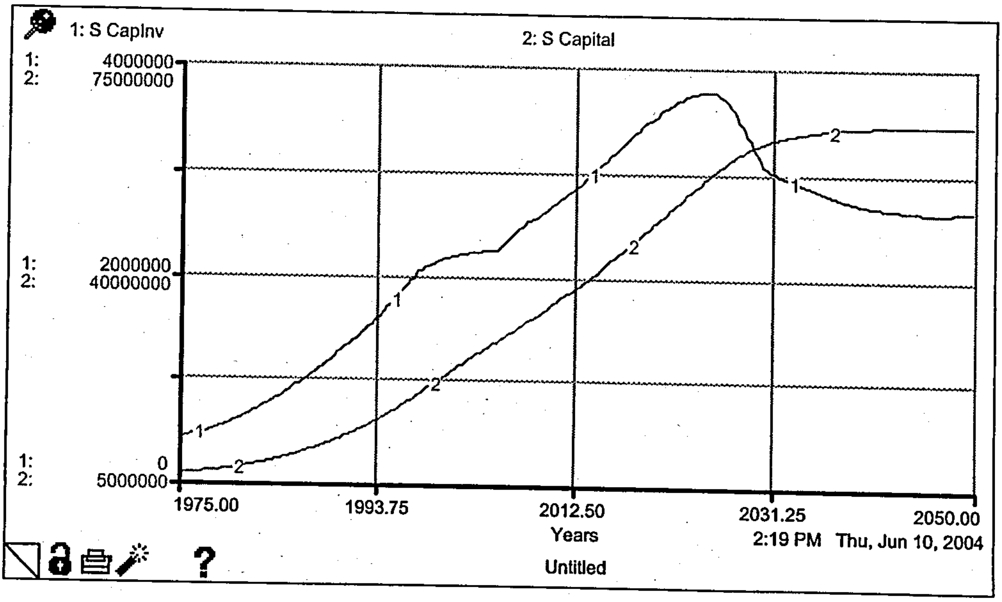


Figure 9.5. Capital stock and capital investment for South in "distortion in the balance of goods exchanged in favor of North" scenario

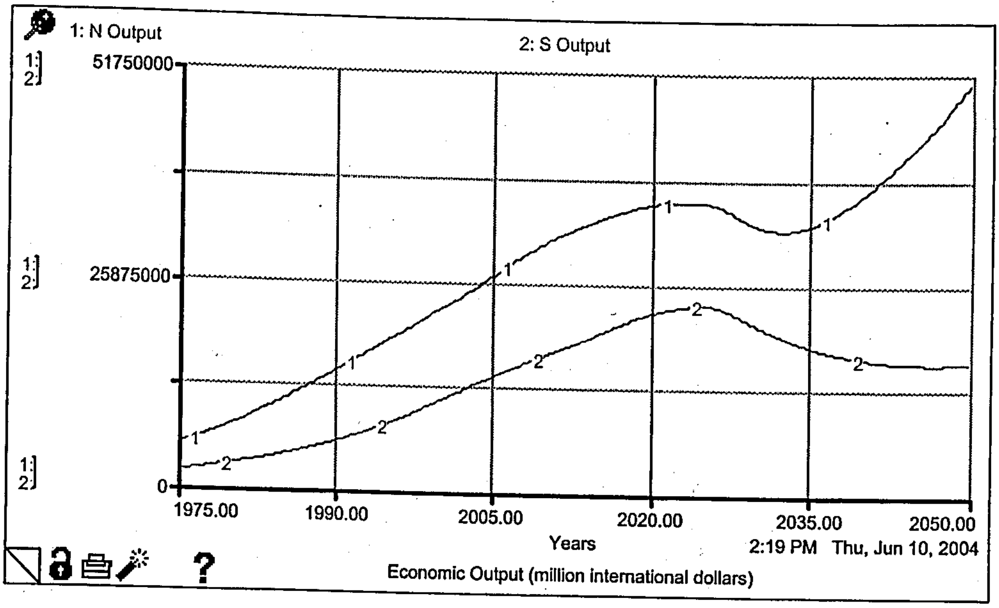


Figure 9.6. Gross economic output for North and South in "distortion in the balance of goods exchanged in favor of North" scenario

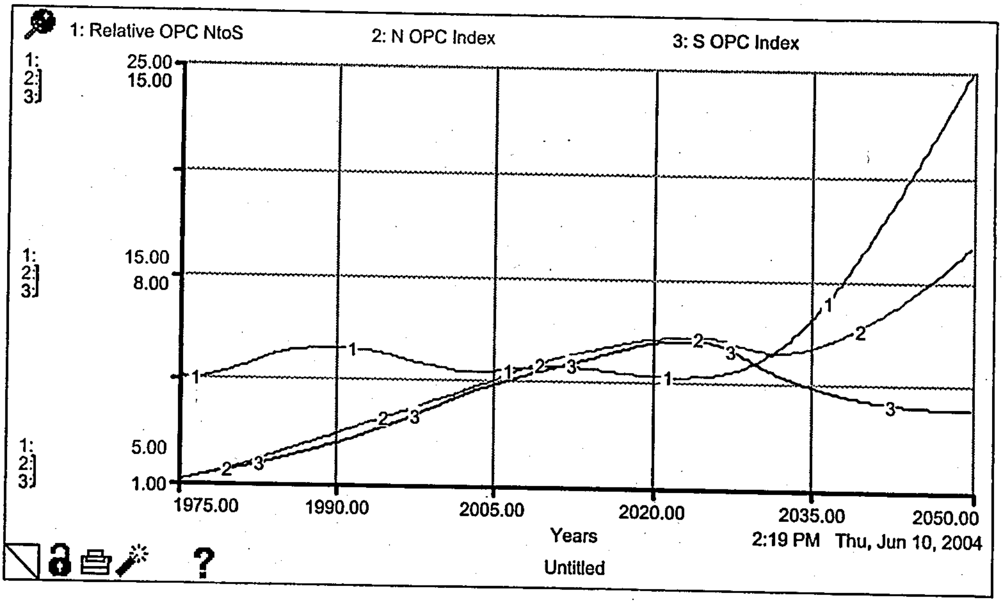


Figure 9.7. Indexed economic output per capita in "distortion in the balance of goods exchanged in favor of North" scenario

9.4. Optimistic Non-Renewable Energy Reserves

In this scenario, it is assumed that actual levels of both discovered and undiscovered non-renewable resource reserves are far above the estimated levels. So, initial stock levels used for the base run are doubled for this scenario.

In terms of economic output, both North and South experience an uninterrupted growth in the time horizon covered by the run. The gap between the per capita output levels experienced in blocks seem to widen, but the North-South output per capita ratio decreases to a level of 7 from the level of 12, which is the highest level observed in 1990.

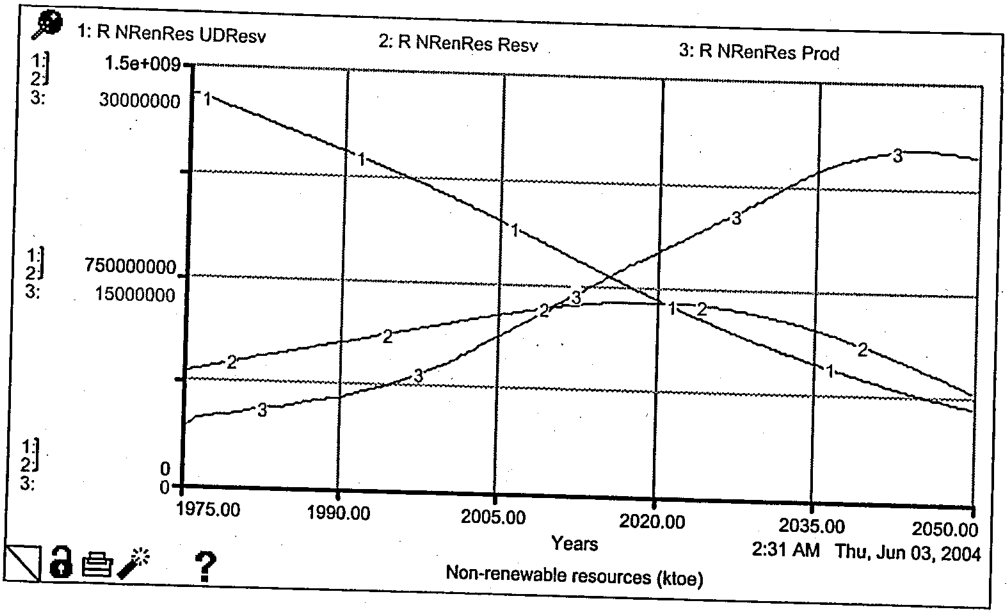


Figure 9.8. Global non-renewable resource production and reserve levels in “optimistic non-renewable energy reserves” scenario

Although an energy shortage is not experienced in this run, patterns observed in the energy resources transition and the non-renewable energy resources production reveal that possibility of such a crisis is unfortunately not eliminated, but just delayed and pushed out of the time horizon of the run. As seen in Figure 9.8, global non-renewable resources production reaches its peak around 2040 and starts to decline.

Apart from those, increased availability of non-renewable resources yields a serious environmental problem. As blocks respond slower in shifting to renewables, non-renewable resource usage originated emissions of CO_2 continue to increase. This in turn results in atmospheric CO_2 levels to reach 650 ppm level by 2050 (see Figure 9.9). Increased emission rates and the atmospheric concentration level of CO_2 affects the life expectancy in both blocks and a slight decrease is observed after 2025.

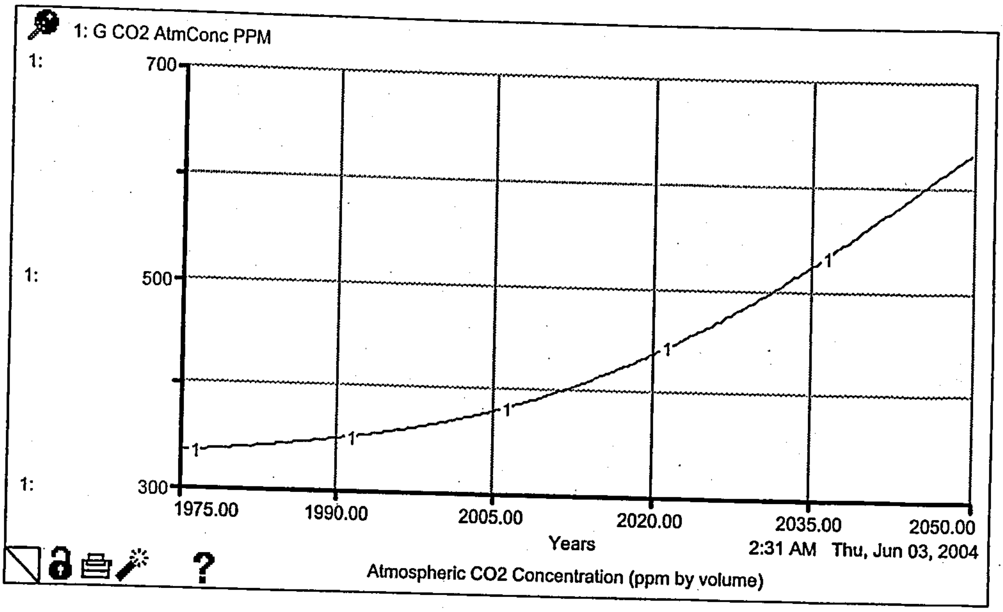


Figure 9.9. Atmospheric CO_2 concentration in "optimistic non-renewable energy reserves" scenario

9.5. Decreasing Energy Intensities after Year 2000

Based on the historical data, energy needed per output is assumed to converge to 0.2 after year 2000. In the first instance of the scenario, it is assumed that energy intensities of all blocks decrease gradually to 0.15 until year 2010. This change results in a significant increase in the economic output of South and postpones the energy shortage for a while. However, no significant change is observed in overall patterns. Hence, a second instance is tested by gradually decreasing the energy intensity to 0.1 level until year 2030. This serious, and probably very hard to attain decrease results in significant pattern changes.

Even with such a decrease in energy intensities of the blocks, an energy crisis still exists in the time horizon of the run. However, in this case, crisis is delayed about 15 years. In terms of the patterns observed in gross output, behavior of both blocks are very similar to the ones observed in the base run, only the peak points differ.

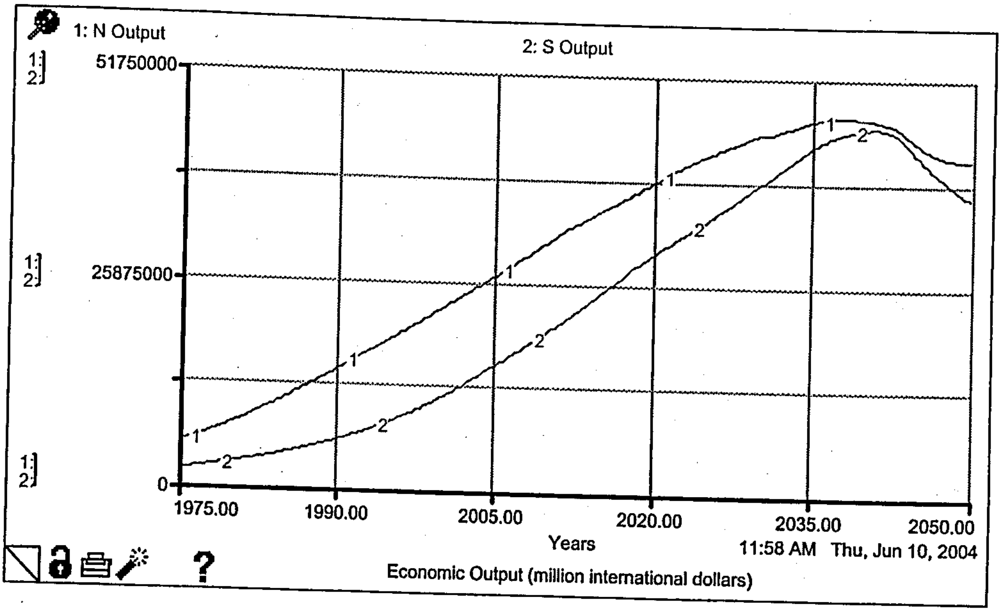


Figure 9.10. Gross economic output in "decreasing energy intensities after year 2000" scenario

The main differences are observed in per capita output figures and resource usage patterns. When the graph related to output per capita levels of blocks is studied, it is seen that South experiences a rapid growth, and the North-South output per capita ratio continues to decrease after year 2000 differing from the base run. Although a relative worsening is observed during the energy crisis, it is milder compared to base run. This change is mainly due to the population dynamics of the South. In the former cases, including the base run, economic slowdown in South is experienced in a period in which population is still growing very fast. So, in such a setting an even small slowdown in economic growth yields a significant decrease in per capita output due to increasing population base. However, in this scenario population of the South seems to be close to stabilization level in the time of crisis. Hence, the period of economic growth slowdown is coupled with an almost stable population and impact of economic slowdown on per capita output is felt less (see Figure 9.11).

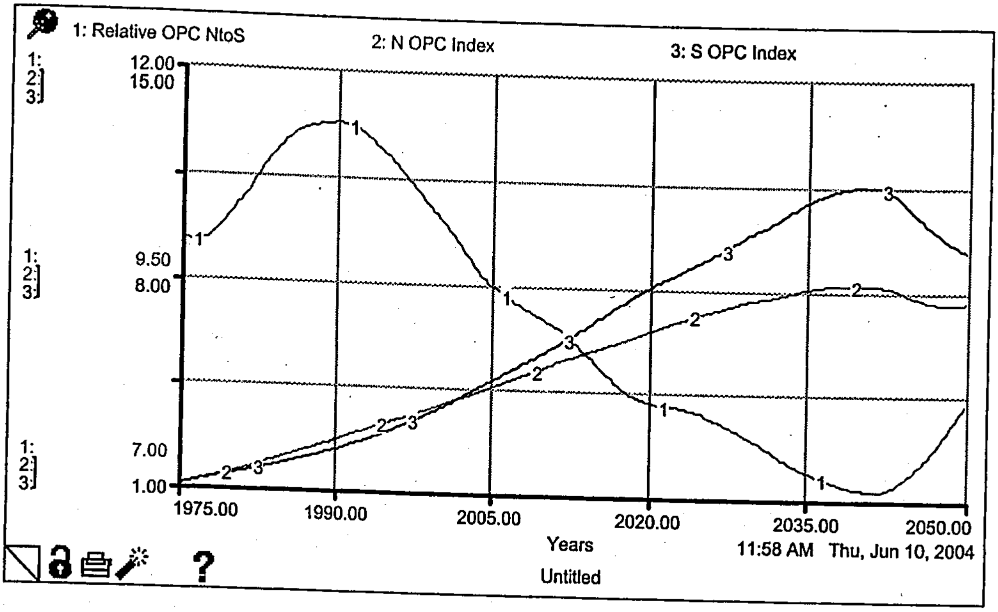


Figure 9.11. Indexed economic output per capita in "decreasing energy intensities after year 2000" scenario

When the non-renewable energy resources usage patterns are studied, it is seen that usage levels of North almost stabilize after 2005, due to the significant decrease in the energy intensity. On the other hand, such a decrease in energy intensity fails to compensate the effect of increasing economic activity on resource usage, and non-renewable resource usage in South demonstrates an upward-sloped curve until energy shortage appears. However, it is important to note that increase rate of the South originated demand is considerably less compared to base run. These changes in resource usage patterns also affect the global resource production and the reserve levels. As seen in Figure 9.13, global non-renewable resource production reaches a level close to the peak, and sustains that level during a period of almost 25 years.

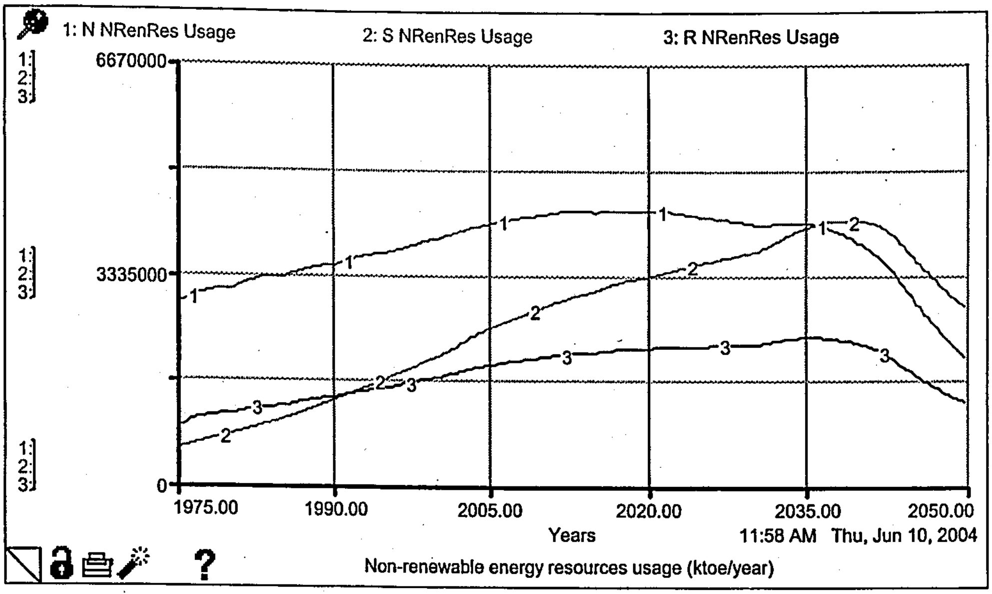


Figure 9.12. Non-renewable energy resources usage in "decreasing energy intensities after year 2000" scenario

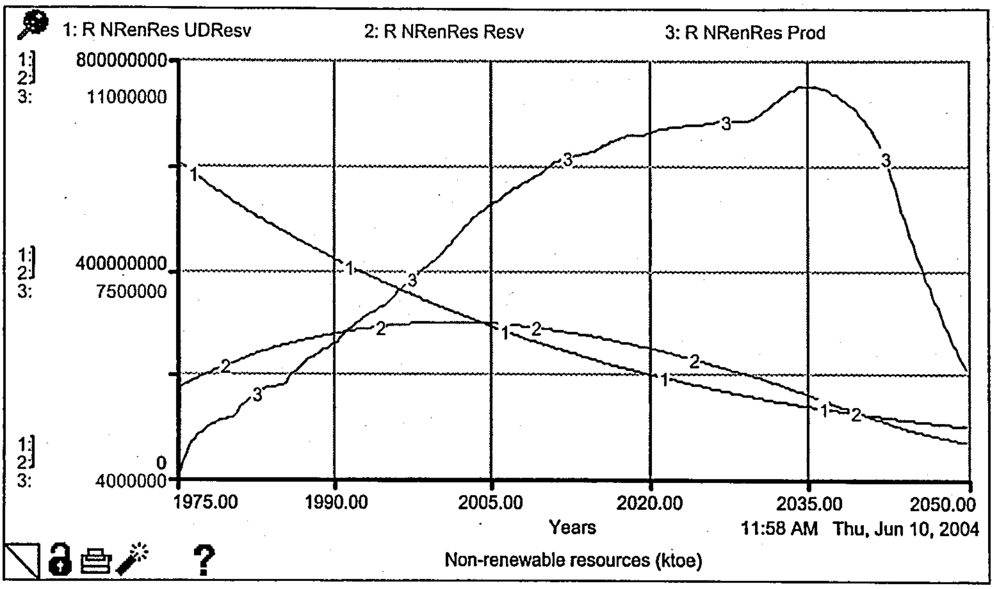


Figure 9.13. Non-renewable energy resources reserves and production in "decreasing energy intensities after year 2000" scenario

Parallel to the non-renewable resources usage patterns, increases in the CO_2 emissions are slower, and it even stabilizes in North. A direct consequence of this change is the decreased atmospheric CO_2 concentration by 2050. Slowly increasing emissions also result in fewer loads on the oceanic sink, and the carbon content of the oceanic sink is observed to be lower than the former cases. This indicates less damage to the carbon buffer system of oceans.

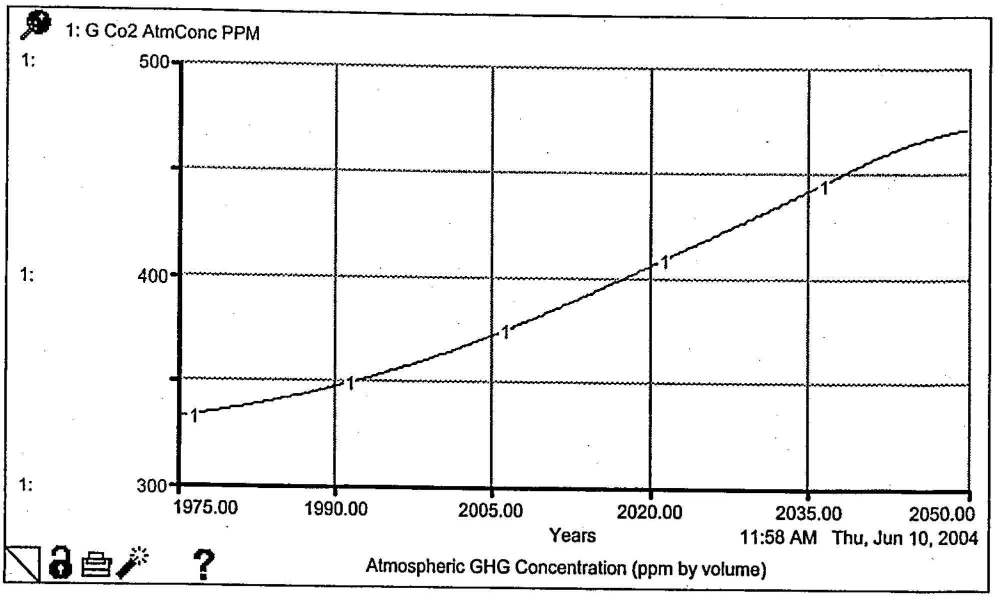


Figure 9.14. Atmospheric CO_2 concentration in "decreasing energy intensities after year 2000" scenario

Finally, coupling of uninterrupted per capita output growth and gradual increase in global pollution results in significantly higher life expectancy levels at South. In this scenario, life expectancy level of South past the 70 years level by the end of the run. Although such an increase is expected to induce population growth, formerly decreased fertility level in South (as a consequence of increased welfare) offsets this effect.

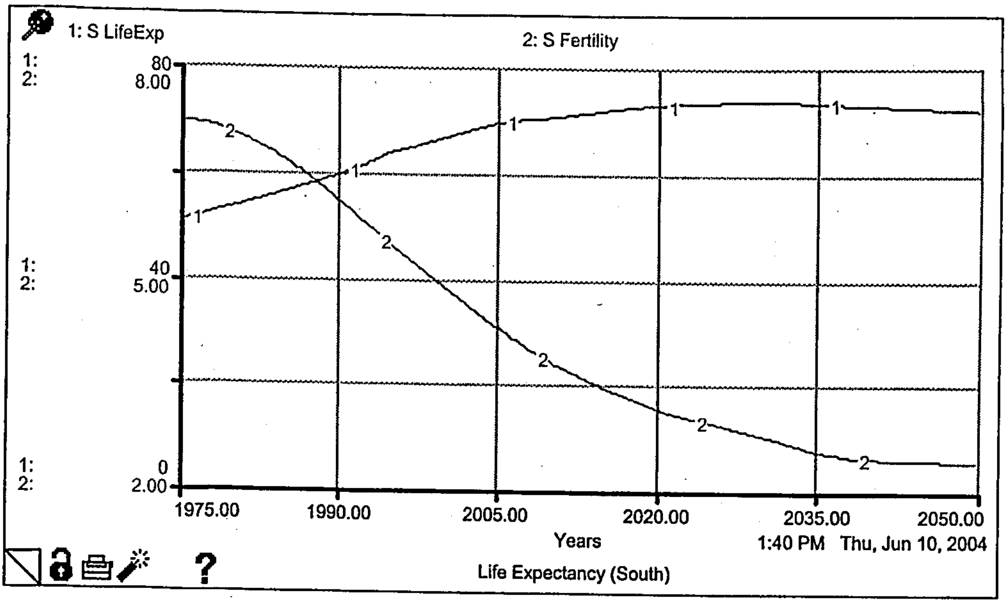


Figure 9.15. Life expectancy and fertility patterns for South in "decreasing energy intensities after year 2000" scenario

9.6. Decreasing Buffer Capacity of Oceans

In the base run, single factor that affects the buffer capacity of oceans is the amount of CO_2 dissolved in the oceans. However, there are several other factors hypothesized to affect the CO_2 uptake capacity of the oceans, including mean temperature, biological composition, and the currents. In this scenario, an exogenous factor assumed to prevail that gradually decreases the CO_2 uptake capacity by 30 per cent between the years 2005 and 20025.

As expected atmospheric CO_2 concentration stays significantly higher compared to the base run, and reaches the 540 ppm level by 2050. Although this increase results in decreased life expectancies in both blocks, this effect is observed to be minor. No significant implication of this scenario is observed in economic and energy systems.

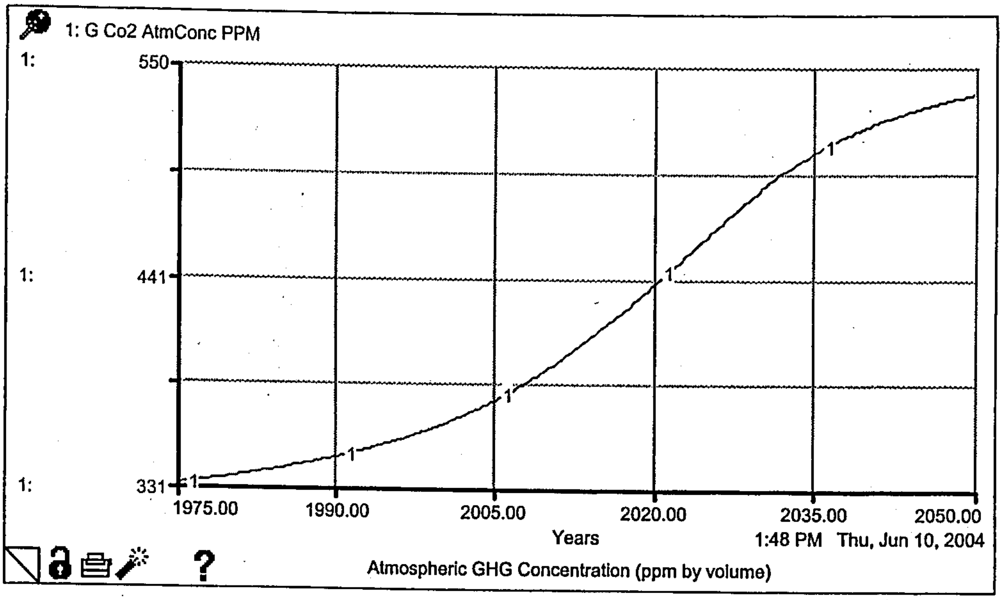


Figure 9.16. Atmospheric CO_2 concentration in "decreasing buffer capacity of oceans" scenario

9.7. Pessimistic Technology Transfer Rate after year 2000

As mentioned in the model description, the output-capital ratio is determined by the effects of capital deepening and capital technology development. In this scenario, global impacts of a poor technology development experience in South are studied through gradually slowing down the technology transfer from North to South by 50 per cent after year 2000. Various implications of such a scenario are observed for different systems and blocks. First of all, gross output of South fails to reach the levels of the base run, as expected. On the other hand, North seems to benefit from this scenario due to delayed energy resources shortage. As South originated resource demand is also lower compared to base run, the energy resources shortage experienced becomes a less severe crisis at global scale. Hence, energy scarcity based economic slowdown seems to be less significant for North.

Slowed growth in economic output coupled with the population growth, which stays high due to poverty, results in an inverted-U shaped pattern in the per capita output (see Figure 9.18). By 2050, per capita output almost drops to 1975 level. Additionally, the ratio of output per capita figures of North and South blocks reveals a widening welfare gap throughout the simulation time.

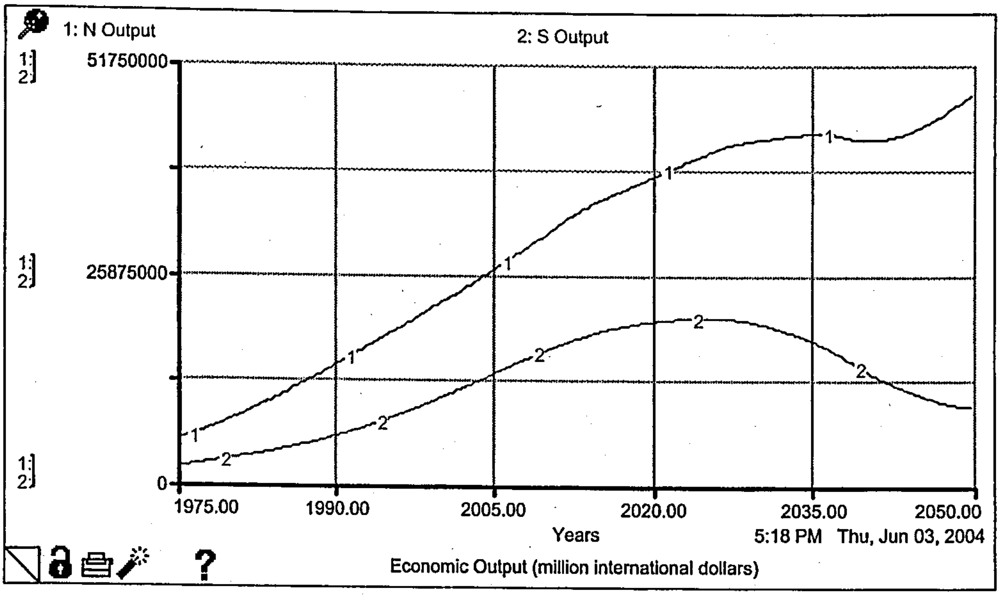


Figure 9.17. Gross economic output in "pessimistic technology transfer after year 2000" scenario

Change in the pattern of economic output directly affects the South originated resource usage and CO_2 emissions. As it can be seen in Figure 9.19, South based emissions stay at significantly lower levels. Naturally, a lower atmospheric CO_2 concentration level is expected as a result of this decrease, but it is not the observed situation. By 2050, atmospheric CO_2 is observed to be around 510 ppm, which is very close to the values observed in the base run. This indifference is mainly caused by the increased North originated emissions. As indicators for non-renewable resources are more optimistic due to the decreases demand of South, progress of North in transforming to renewables seem to slow down. As a result, between 2000-2050 period, North seems to use more non-renewable resources compared to the base run.

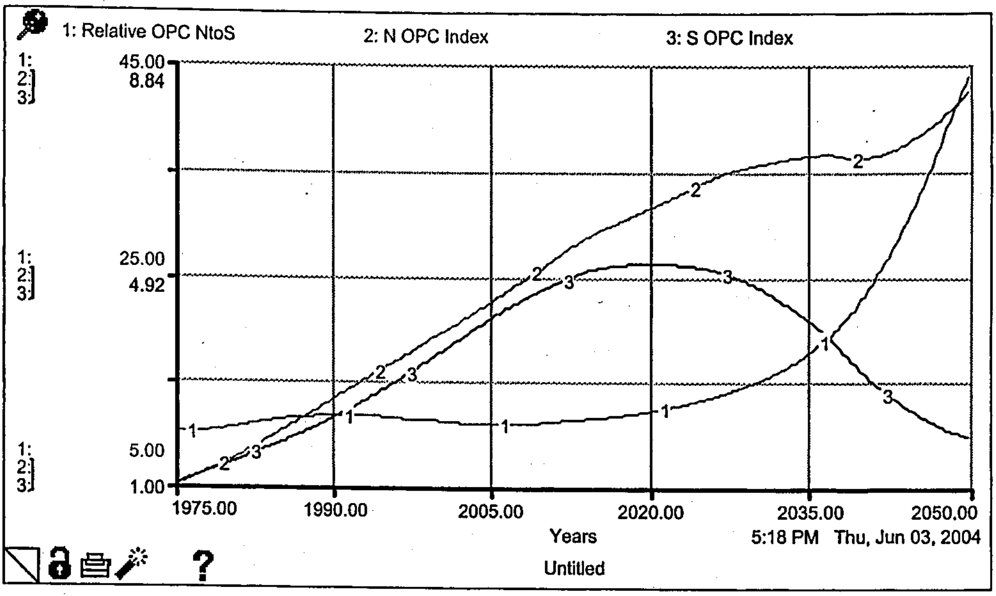


Figure 9.18. Economic output per capita in "pessimistic technology transfer after year 2000" scenario

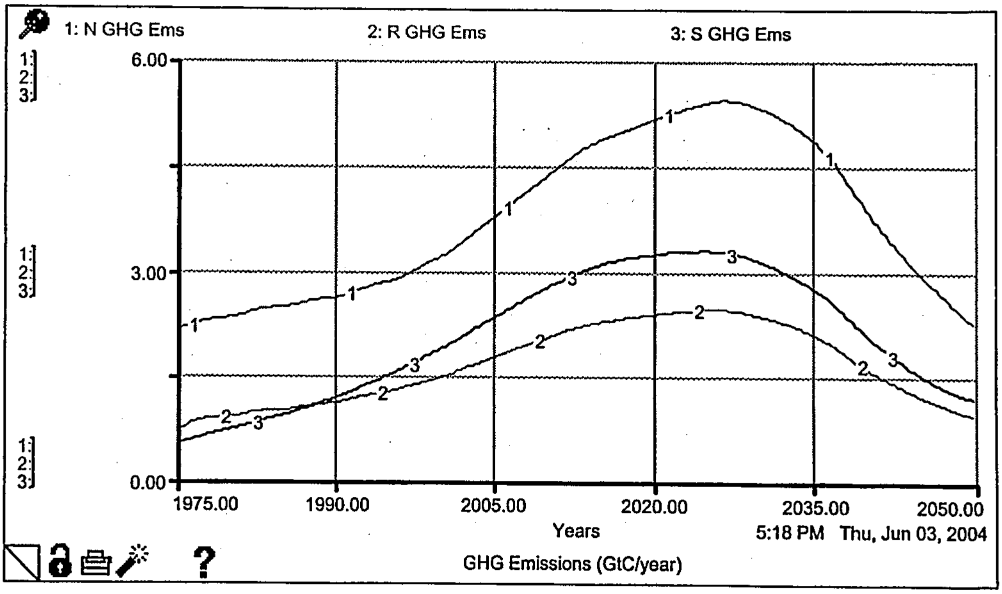


Figure 9.19. CO_2 emission levels observed in "pessimistic technology transfer after year 2000" scenario

10. POLICY ANALYSIS

In this section, outcomes of certain policies proposed in order to close the welfare gap, prevent the energy crisis and reduce CO_2 emissions are tested on the model. Policy specific structural modifications and variables changed are mentioned in the sections belonging to related policies. For each policy, variables that are aimed by the policies are studied primarily. Additional to those, the effects of policies on other systems are also mentioned.

10.1. Increased Technology Transfer after Year 2000

As a consequence of faster technology adoption from North, an improvement in the output-capital ratio is observed, which in turn results in higher growth rates for economic output. A significant welfare improvement is observed for the South block in the period prior to energy shortage, such that North-South output per capita ratio almost halves in this period. Conclusions up to this point are almost contrary to the ones observed in the "pessimistic technology transfer rate after year 2000" scenario. However, general behavior in the energy shortage era is almost the same; a significant per capita output decrease and a widening welfare gap between blocks (see Figure 10.2). This common problem encountered in both of these scenarios is mainly due to the fast growing population base of South. Dynamics of population do not tolerate any slowdown in the economic output and such a case results in dramatic decreases in the output per capita figures.

Additionally, South block seems to take the lead in CO_2 emissions and becomes the leading CO_2 emission source on global scale (see Figure 10.3).

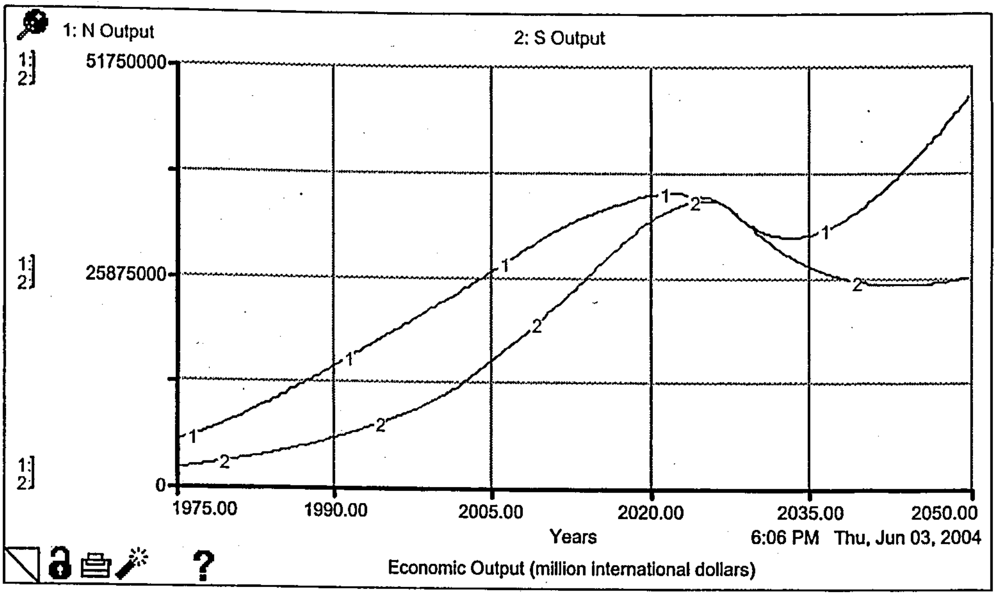


Figure 10.1. Gross economic output in "increased technology transfer after year 2000" policy

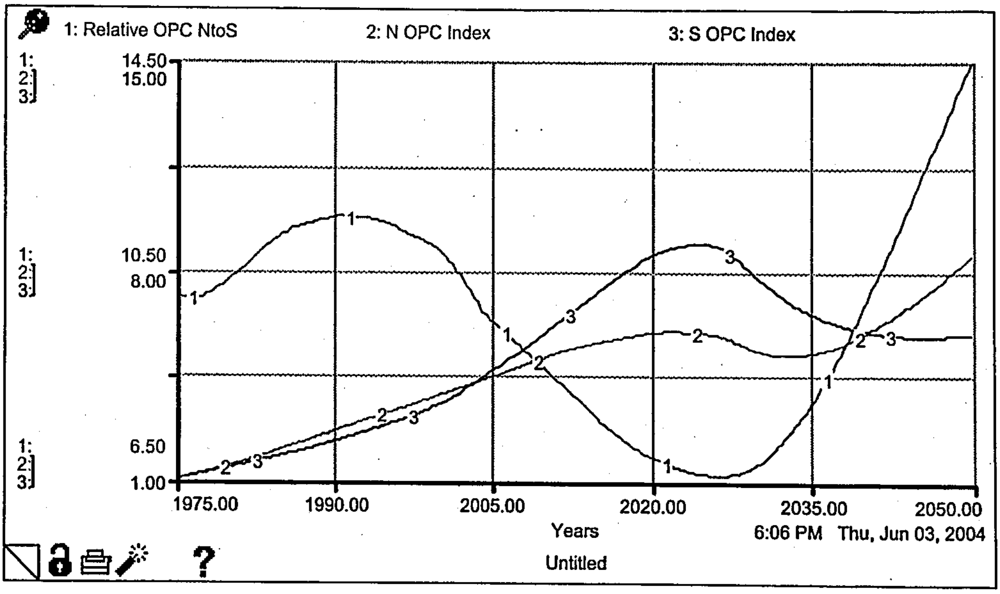


Figure 10.2. Output per capita levels observed in "increased technology transfer after year 2000" policy

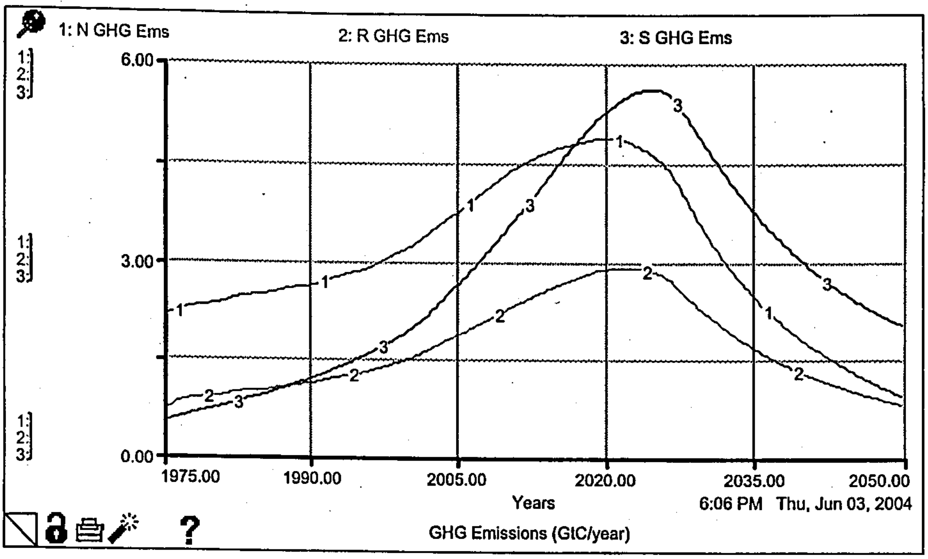


Figure 10.3. CO_2 emissions in "increased technology transfer after year 2000" policy

10.2. Increasing Targets for Renewable Energy -1

It is assumed that after year 2000, target levels for renewable energy supply fraction are increased gradually to 90 per cent level by year 2050. In this version policy is assumed to be applied at global scale, hence both North and South apply this policy. According to this new policy, energy resources transition starts well-before the perception of critical signals regarding non-renewable resources' availability.

In the simulation runs according to this policy, North block manages to build up the required energy capacity and completes the target transition by 2050. During this target realization process, North benefits from its vast investment power. Using the identical preferences and goals, South is observed to fail in meeting the target transition from non-renewables to renewables. Additionally, investment required for renewable energy facilities, especially after year 2020, results in a serious slow down in economic output for South, as seen in Figure 10.4. While consequences for South do not differ considerably between this policy and the base run, it is seen that with such a rapid shift to renewables North avoids an interruption in the growth of economic output (see Figure 8.5 and Figure 10.4).

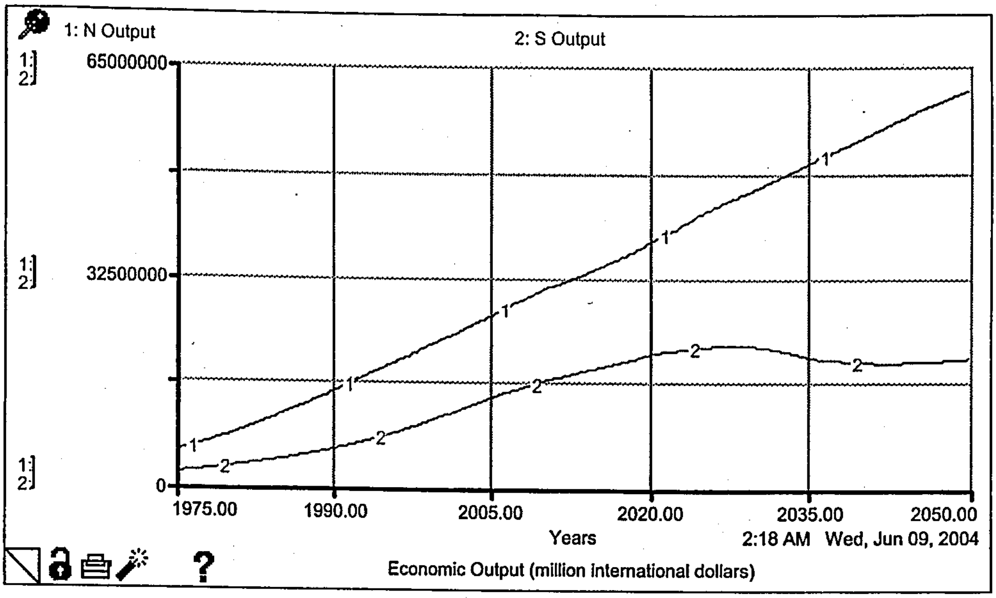


Figure 10.4. Economic output by North and South with "increasing targets for renewable energy-1" policy

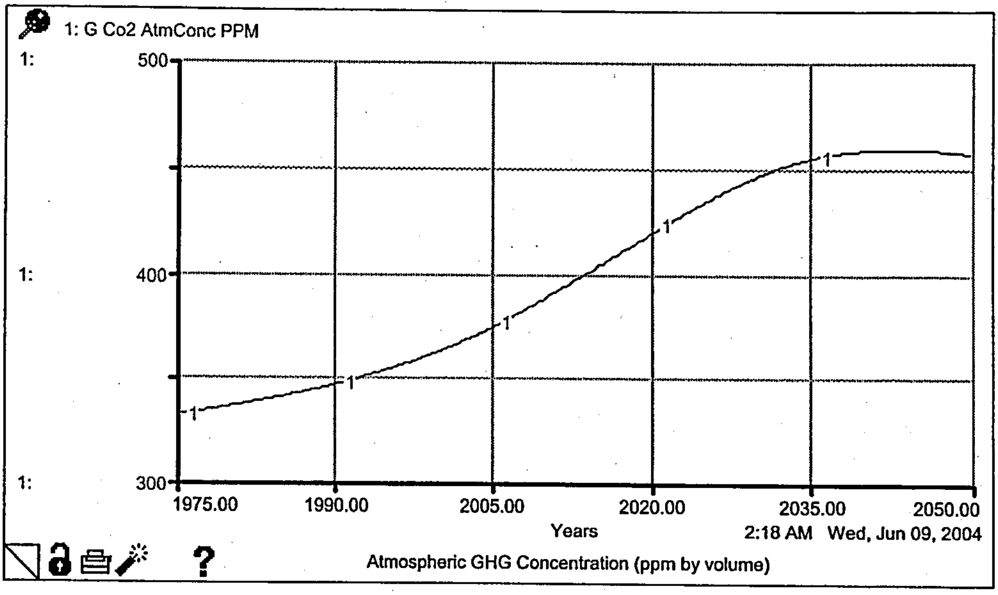


Figure 10.5. Atmospheric CO_2 level with "increasing targets for renewable energy-1" policy

This policy results in a decrease in the atmospheric concentration of CO_2, which is observed to be around 450 ppm by 2050, as seen in Figure 10.5. At the same time, non-renewable energy resources' usage significantly decreases and it is seen that almost 25 per cent of the global reserves remain unused by 2050 (see Figure 10.6). Based on this observation, policy used in this run is modified and re-tested.

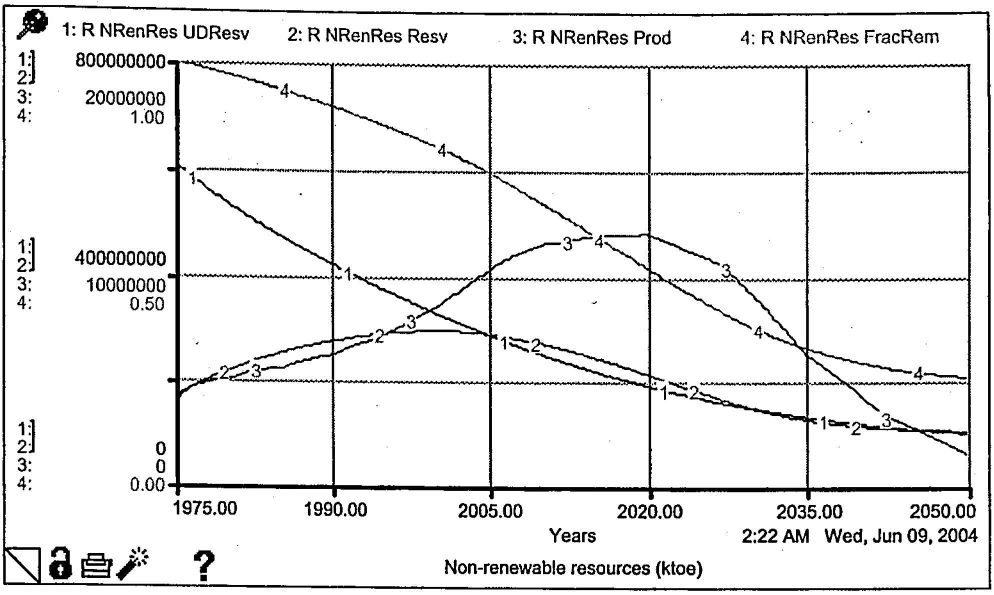


Figure 10.6. Non-renewable energy resource reserves with "increasing targets for renewable energy -1" policy

10.3. Increasing Targets for Renewable Energy-2

Based on the observation that a rapid increase in renewable energy targets damages the economic growth of South and a considerable amount of non-renewable reserves remains, policies used for North and South are differentiated. In this second policy regarding renewable energy supply targets, North is assumed to use the policy employed in the former case. Contrary to the former case, targets for South are significantly relaxed. According to this new policy, target fraction of renewable energy supply increases gradually to 30 per cent level by year 2050. This can be evaluated as an allowance for South in non-renewable energy resources usage.

As it can be seen in Figure 10.7, no major change is observed for North. However, economic slowdown due to intensive investment to renewable energy capacity seems to disappear for South in this case. South experiences a milder shift to renewables compared to the case with the former fast transition policy. Although an economic slowdown after year 2035 is observed, it is mainly due to another cause; decreased non-renewable resource production. It is also important to note that economic output levels attained in this run are the highest of all runs up to this point, and output patterns of both blocks are almost uninterrupted. In Figure 10.8, per capita output figures are presented with the North-South output per capita ratio. According to this plot, South seems to sustain the relative ratio of per capita output with respect to North until last 15 years of the simulation, during which relative situation of South worsens compared to North. As in the former experiments, rapid population growth coupled with the economic slowdown results in a relative decrease in per capita output.

Although economic indicators observed with this policy are better than the former case, environmental indicators are a bit poorer. First of all, fraction of remaining resource reserves decreases to 17 per cent by 2050 (see Figure 10.9), and atmospheric CO_2 concentration, which increases to 480 ppm level from the 450ppm level in the former policy (see Figure 10.10).

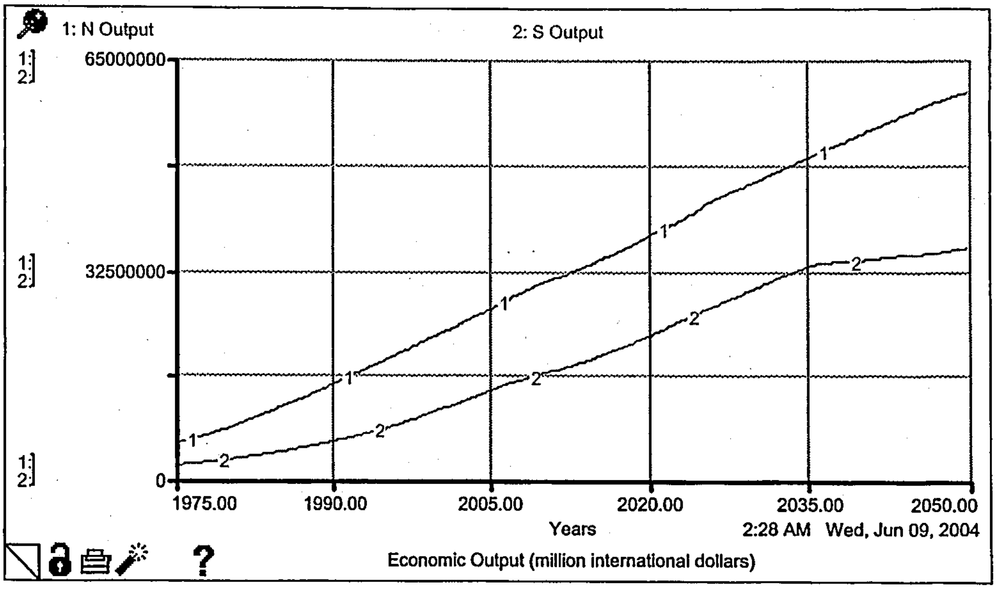


Figure 10.7. Economic output by North and South with "increasing targets for renewable energy-2" policy

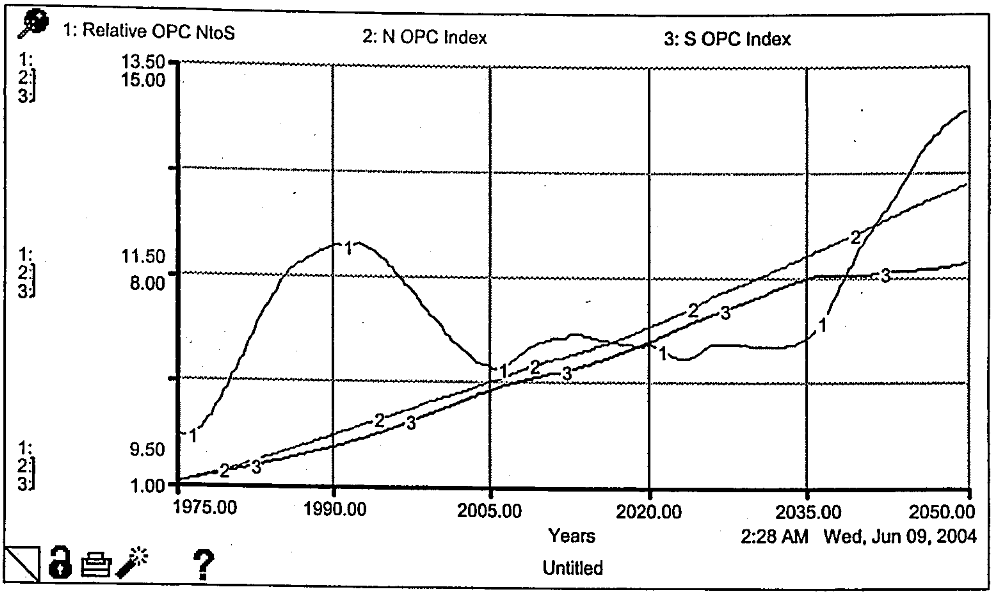


Figure 10.8. Indexed per capita output for North and South with "increasing targets for renewable energy-2" policy

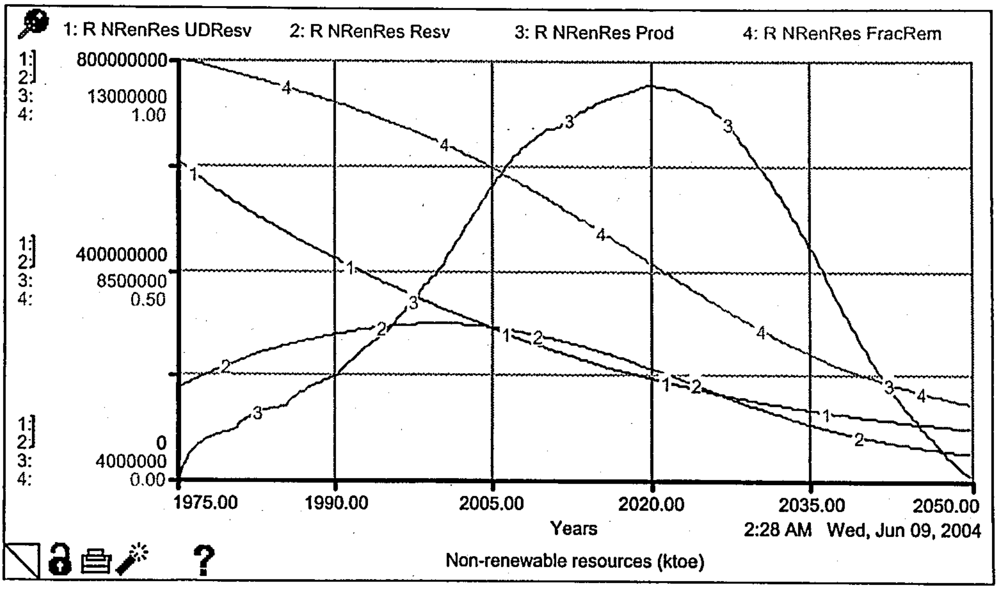


Figure 10.9. Non-renewable energy resource reserves with "increasing targets for renewable energy-2" policy

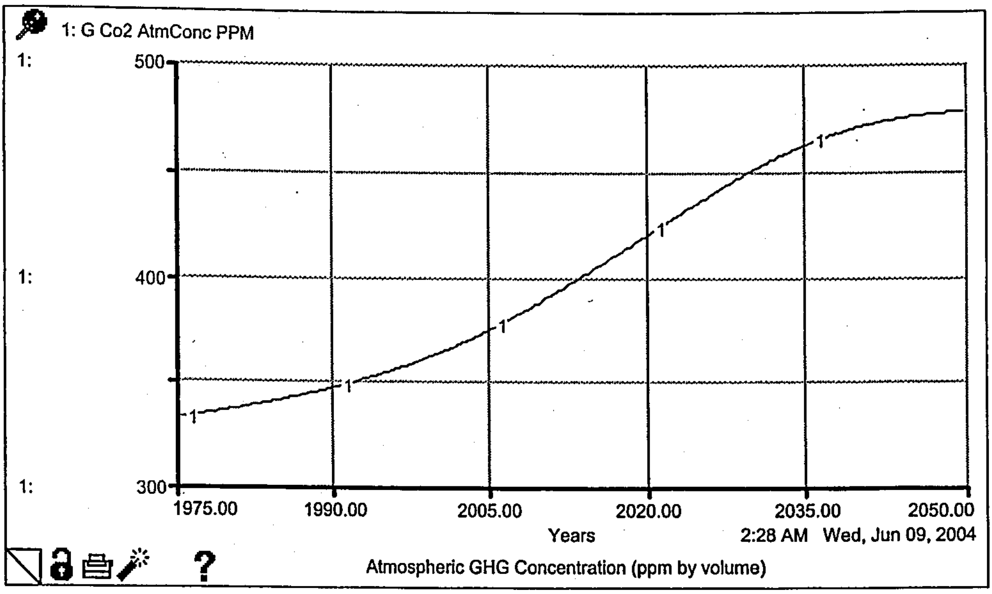


Figure 10.10. Atmospheric CO_2 level with "increasing targets for renewable energy-2" policy

10.4. North Supported Energy Transition in South

In this case, a policy towards supporting the energy transition in South by the capital from North is tested. According to this policy North provides South capital to be invested in renewable energy sector, as long as non-renewable resource usage prevails in North. The amount of the support is directly proportional to the amount of resources consumed by North. Additionally, a fast energy transition policy is assumed to be employed in South as a condition of this support. No change in the energy transition policy of North from the one used in the base run is assumed to exist.

The setting of this policy provides striking results. First of all, North originated support provides an important relief from required intensive investment in a fast transition policy, and South manages to complete a significant portion of energy transition, which is almost 70 per cent, by year 2050. This transition prevents the significant growth in non-renewable resources demand of South, and global resource consumption is dominated only by North, as seen in Figure 10.11.

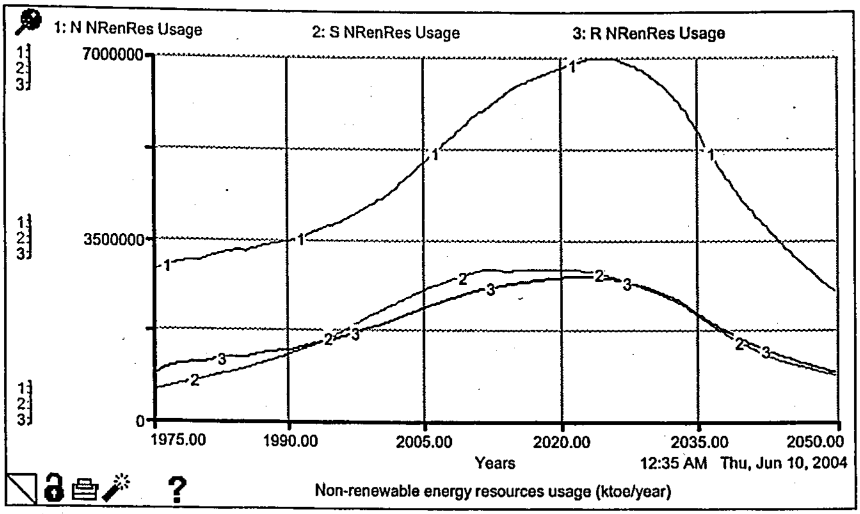


Figure 10.11. Non-renewable resource usage with "North supported energy transition in South" policy

As a consequence of decreased global resource demand, North experiences a slower transition to renewables, because of the postponed scarcity indicators. Consequently, postponed resource shortage affects non-renewable resource dependent North economy around 2035. However, the impact of the shortage is minimal for South. Output patterns for both blocks are given in Figure 10.12. Most striking output of the policy is the closing output per capita gap between blocks. As it can be seen in Figure 10.13, North-South output per capita ratio starts to decrease after 2020.

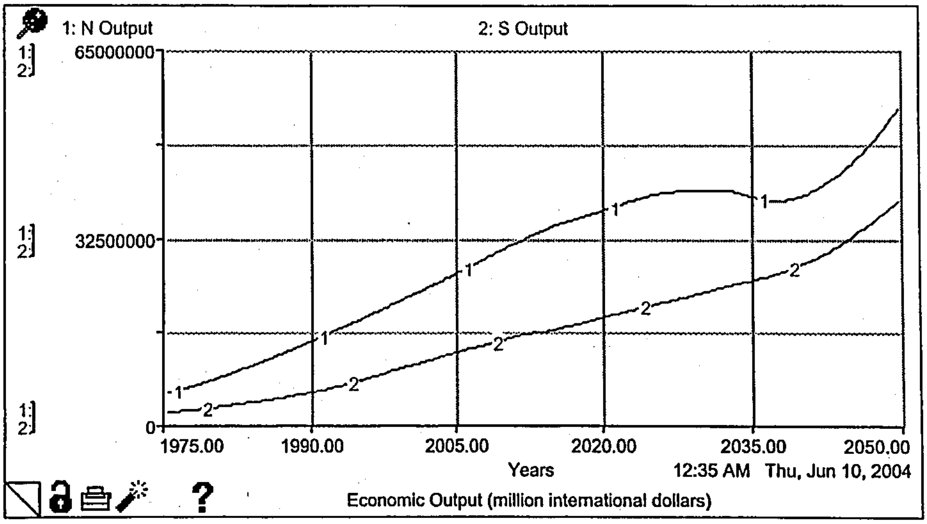


Figure 10.12. Economic output by North and South with "North supported energy transition in South" policy

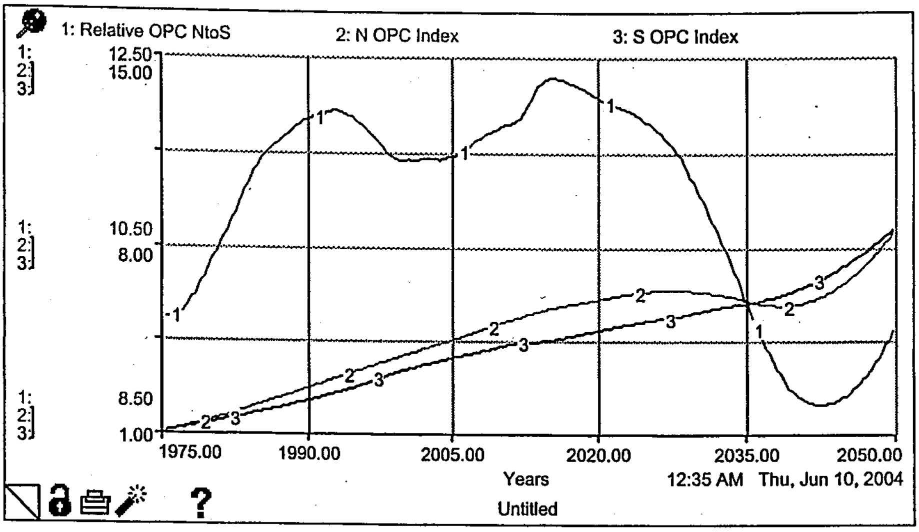


Figure 10.13. Indexed per capita output for North and South with "North supported energy transition in South" policy

Apart from economic indicators, increased level of per capita output levels results in increased life expectancy levels at South. This increase results in a slowdown in the death rate, and the stabilization level of the global population is increased a bit above 8 billion people. No significant change is observed in CO_2 levels, as North compensates for the decreased non-renewable resource usage by South.

10.5. Increasing Non-Renewable Resources Production

According to this policy, it is assumed that non-renewable resources production capacity is doubled, such that production rate is two times the one used in the base run with identical reserve levels. Overall behavior of the system is very similar to the cases observed before.

Major difference worth mentioning is the declining phase of the resource production. Compared to the base run, the peak level of resource production is higher and also the rate of decrease in the production is faster. This fast decline results in an energy crisis, which gets more severe (in terms of fraction of unsatisfied demand) in a shorter time compared to the base run. Such a fast growing energy problem forces country blocks to complete faster energy transitions, which demands enormous energy investment. Implication of this requirement is evident in Figure 10.15. Recession in the economic output in South is considerably more severe, and there is no sign of recovery by 2050. On the other hand, recession in North also seems to be worse, but North manages the transition as in the base run.

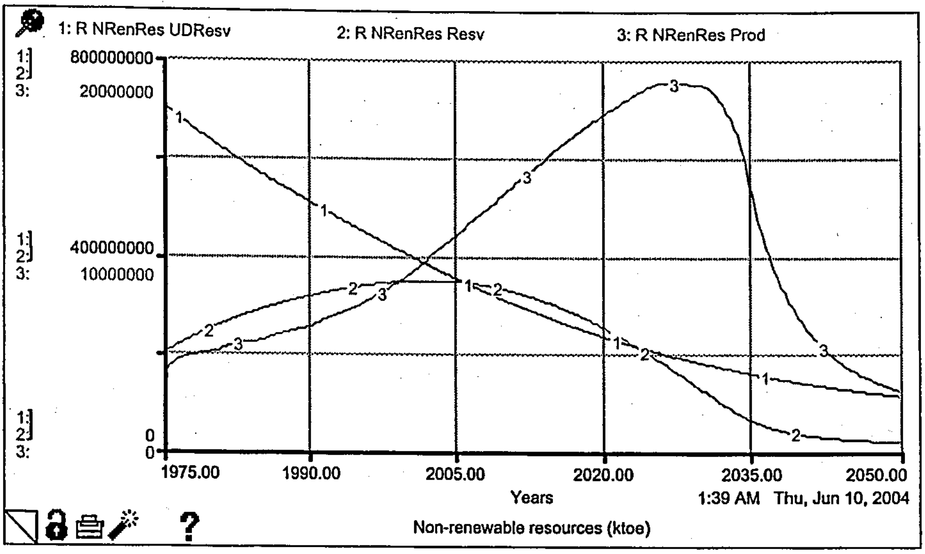


Figure 10.14. Non-renewable energy resources reserves and production with "increasing non-renewable resources production" policy

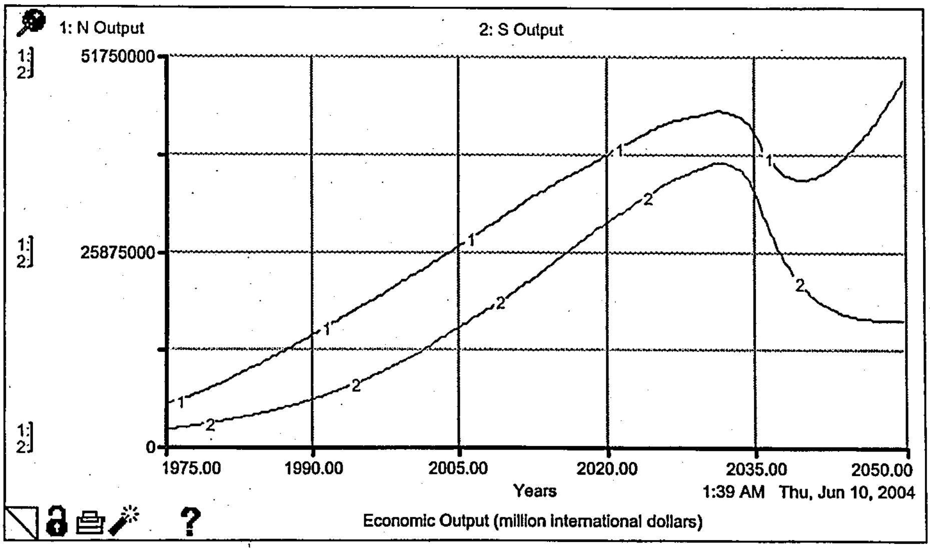


Figure 10.15. Gross economic output of North and South with "increasing non-renewable resources production" policy

11. CONCLUSION AND FURTHER RESEARCH

Most models about the global sustainability problem treat the world as a homogenous, single system without any individual nation distinction. However, economic and demographic heterogeneity of nations is a major issue regarding the sustainability of the global system. This study aims to study long-term sustainability of the economic, environmental and social systems at a global level. While doing so, the research uses a typical clustering of nations with respect to development and welfare levels and focuses on probable affects of differing internal dynamics of the developed (North) and developing (South) country blocks on global sustainability. As the problem is dynamic in nature and includes complex feedback relations, a dynamic simulation model is built with system dynamics methodology. According to the context defined, the model covers population, economic activity, energy supply, and pollution issues for two separate country blocks; developed (North) and developing (South) countries.

The model, after being completed, is validated through well-defined validation procedures. Initially, the structure of the model is tested in order to detect flaws by using extreme input values and by observing the sensitivity of the model output to certain variables. The model is evaluated to be structurally valid following these tests, and then the model output is compared with the available actual data, in order to test the behavioral validity. The simulation period between 1975 and 2000 is used for these comparisons. After comparing major variables with their actual values, the model behavior is evaluated to be a satisfactory representative of the actual data in terms of both dynamic pattern and numeric proximity.

According to the reference behavior of the model obtained with current practices, it does not seem viable to close the welfare gap between North and South blocks. An economic output level that provides the living conditions of North to crowded South population is observed to be far away from feasibility with the currently known environmental capacity in supplying key inputs and absorbing key pollutants. Hence, a non-renewable-resource-based economic growth that is required for the growing South population takes the global system even closer to its limits. By such a growth, South becomes the leading resource user and pollution emitter, and this in turn results in very rapidly increasing global pollution levels and resource depletion rates. Life expectancies in both blocks decrease due to increasing pollution, and both blocks fail to shift to alternate energy inputs as scarcity comes to scene very fast. Hence such an economic growth path for South is not an option for sustaining the global system and attaining the welfare equality.

Throughout the scenario analysis stage, population dynamics of South is identified as the major problem for South's well-being. Population grows so rapidly that a very high economic growth rate is required just to sustain the welfare level in 1975. Additionally, any slow down in the economic growth results in a significant decline in per capita gains, as population continues to grow rapidly. Also at a macro level, stabilization level of South populations determines the global load of social and economic systems on the environment.

In the scenario runs, it is observed that energy resource usage patterns are insensitive to the initial reserve levels. Unless currently known preferences and valuations in non-renewable energy resources usage are altered, delays embedded in the perception and reaction processes related to energy transition makes an energy crisis inevitable. Additionally, decreasing the energy intensity of the economic activity by itself also fails to completely alter both energy and pollution crises. The demand for resources grows so fast that, only unrealistic improvements (like 50 per cent reduction in global energy intensity by 2010) can result in tangible improvements.

Trade between North and South blocks is observed to be vital for the development of South. In the two-segment economic framework, North positions as the global supplier of goods with high technology content. In further stages of development, South's dependence on these goods for investment increases significantly. Hence, any factor disturbing the flow of these goods to South seriously disturbs South's development.

In the policy analysis stage it is concluded that for the cases in which both economies stay dependent on non-renewable resources, North benefits from policies that prevent South's economic growth, as growth of South indicates faster resource depletion. In such policies, South initially grows rapidly, but then is severely damaged due to resource scarcity. Meanwhile, non-renewable resource dependent growth policies result in higher CO_2 levels and almost complete depletion of resources.

A common conclusion from all policies tested is that the usage of finite non-renewable resources should be altered as soon as possible. It is evident that cumulative load of growing South and North is too much for the finite capacity of the earth, in terms of both providing the resources and absorbing the prevailing pollution. Best performing policies in terms of pollution, development and welfare gap are the ones supporting the transition of the blocks to alternative clean energy resources as soon as possible. Also it is observed that an energy scarcity due to depletion of non-renewable resources results in an economic recession, which has more serious impacts on South, compared to North. Recovery of South from such a crisis in a reasonable time frame seems plausible only with the investment support of North needed for building alternative, renewable energy capacity. This support may be in the form of technology transfer, investment or aid. However, the nature of this support and its potential debt accumulating consequences, not modeled in this study, must be carefully managed.

The model constructed for this study provides a platform to study the interactions of the North and South blocks in a closed system. In the context defined, only one main economic input (energy) and one representative pollutant (CO_2) is modeled. It would be beneficial to increase the number of main inputs and pollutants that may affect economic performance and health in future research. In another direction, more explicit formulations of the market mechanism and financial flows accompanying physical goods can also provide new important results regarding the connection between the economic systems of both blocks. Finally, covering food supply as another limit to growth, and defining its relations with pollution and population dynamics may be beneficial.

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APPENDIX A: DESCRIPTION OF THE COUNTRY CLASSES

One of the preliminary stages of this study is to identify nations that form the North and South blocks, which constitute the main focus. The major criteria employed in clustering economies either as South or North is per capita domestic income, which is commonly used as an indicator of wealth and development. However, it seems to be unrealistic to draw a single line in the GDP per capita spectrum in order to define the border between these two classes. In such an approach, it is evident that a top member of the South group with respect to GDP per capita will be more similar to a country in the bottom of North class than a regular country in South class in terms of economic and demographic characteristics. In other words, this type of classification results in very similar countries classified under different classes. Additionally, this results in significant in-group heterogeneity for both groups, which is a serious handicap in studying the behavior of a group. Consequently, studying developed and developing countries requires a third class of countries. This class is composed of countries that are in between the formerly mentioned two classes. Some members of this class are similar to South countries, while others are more proximate to North ones. However, none of the countries in this third class can be identified as a typical North or South country. In this study, this class is named to be the Rest-of-the-World (RoW) class. It is used as a border zone between North and South classes by including the countries in between these two classes. Classifying this type of countries in RoW class provided increased in-group homogeneity for North and South classes.

While constituting the North cluster, main purpose is to identify leading countries in the economic development process. Such countries may be characterized as having transformed from a primary commodity based economy to an economy with dominant service and manufacturing sectors. However, relying purely on domestic income per capita figures may be misguiding in determining these economies. In particular, economies solely based on valuable natural resources, like oil-exporting countries have high domestic income per capita figures, but do not fit into the developed country definition used in this study. Hence, addition to the domestic income per capita, composition of the economic output is also used for identifying the more developed countries. After selecting a group of countries that have a GDP per capita above $15000 (for year 2000, in ppp terms), shares of service and manufacturing are studied. In this stage, some of the countries are eliminated from the North group due to their lower shares of manufacturing value added compared to other selected countries. The criterion used in this second stage is to have a manufacturing sector value added above 15 per cent, an agriculture sector value added below 7 per cent and a service sector value added above 50 per cent. These levels are identified after conducting a regression analysis on a set of economic output composition data. The countries dependent on natural resources and countries that have weak manufacturing sector are eliminated from the developed countries cluster in this latter stage.

A set of 18 countries are distinguished by having significantly high both domestic income per capita and manufacturing output per capita figures compared to the rest of the countries. According to this criterion top member of the group is United States and the member at the lower border is Korea Republic, having $55000 and $15000 per capita domestic income in year 2000, respectively (World Bank, 2003). These 18 countries constituting the North cluster are given in Table A.1.

Table A.1. Countries classified as North

North Cluster			
Austria	France	Netherlands	United Kingdom
Belgium	Germany	Norway	United States
Canada	Italy	Singapore	
Denmark	Japan	Sweden	
Finland	Korea, Dem People's Rep	Switzerland	

After identifying the North, remaining 124 countries demonstrate a great variability in terms of economic status and relations with North. As it is discussed above, it is inconvenient to treat these 124 countries in a single country block, as their economic and demographic characteristics vary significantly. In order to eliminate this heterogeneity and to obtain a South block that is composed of developing countries mainly dependent on primary economic output (see Table A.3), a set of countries that have characteristics of neither North, nor South are identified. This set of countries, which are mainly responsible for the heterogeneity in the larger set of 124 countries, are defined to be Rest-of-the-World block countries and they form the border zone between North and South country clusters. This group of countries is mainly composed of two types of economies;

i. Countries having domestic income per capita between $15000 and $3000. This group of countries constitutes the border zone between North and South. Their inclusion to any of these two categories would result in decreasing the economic and demographic homogeneity of that group, so they are excluded from both in favor of preserving the in-group homogeneity.

ii. Countries with high natural resource income. Fossil fuel, especially natural gas and oil exporting countries constitute the majority of this group. This type of economies does not fit the economic development patterns considered in this study. These countries' per capita income figures are very high to be classified as South and their manufacturing and service industry are so weak to be classified as North. As a result, they are excluded from both and handled under the third country cluster. They are mainly the countries excluded from North block at the second stage of the classification process used in forming North block.

As explained in the model overview section, this third group of countries is not modeled in detail as North and South. However, some simple structures are built in order to simulate its expected values for certain variables like pollution generated and fossil fuels extracted. Forty one countries under this category are given in Table A.2.

Table A.2. Countries classified as Rest-of-the-World

Rest-of-the-World Cluster			
Argentina	Ecuador	Mauritius	South Africa
Australia	El Salvador	Mexico	Spain
Barbados	Estonia	New Zealand	Thailand
Belize	Greece	Peru	Trinidad and Tobago
Brazil	Hungary	Poland	Tunisia
Bulgaria	Ireland	Portugal	Turkey
Chile	Jamaica	Romania	Uruguay
Colombia	Latvia	Russian Federation	Venezuela
Costa Rica	Lithuania	Seychelles	
Croatia	Macedonia, FYR	Slovakia	
Czech Rep	Malaysia	Slovenia	

After identifying the countries in the border zone between North and South, remaining 83 countries listed in Table A.3 are identified as the South cluster of this study. These countries have an average GDP per capital level just below $1500, and agriculture as well as primary manufacturing is a dominant economic sector in these countries. Although economic and demographic homogeneity of this group is weaker compared to North, it is evaluated to be satisfactory for the purpose of this research.

Finally, the coverage of the model is investigated and it is seen that total of North and South clusters covered 101 countries and this corresponds to the 78 per cent of world population and 74 of global economic output in 1995. This is the portion modeled in detail and endogenously represented in the model. Including the Rest-of-the-World cluster, model simulates aggregate behavior of a system composed of 142 countries, which represents the 94 per cent of global population and 94 per cent of global economic output.

Table A.3. Countries classified as South

South Cluster			
Albania	Congo, Dem Rep	Jordan	Papua New Guinea
Algeria	Côte d'Ivoire	Kenya	Paraguay
Angola	Cuba	Kiribati	Philippines
Antigua and Barbuda	Djibouti	Kyrgyzstan	Rwanda
Armenia	Dominica	Lao PDR	Sao Tome and Principe
Azerbaijan	Dominican Rep	Lebanon	Senegal
Bangladesh	Egypt	Lesotho	Sierra Leone
Belarus	Eritrea	Madagascar	Sri Lanka
Benin	Ethiopia	Malawi	Syrian Arab Rep
Bhutan	Gabon	Mali	Tajikistan
Bolivia	Gambia, The	Mauritania	Tanzania
Bosnia and Herzegovina	Ghana	Moldova, Rep	Togo
Botswana	Grenada	Morocco	Uganda
Burkina Faso	Guatemala	Mozambique	Ukraine
Burundi	Guinea	Namibia	Vanuatu
Cambodia	Guinea-Bissau	Nepal	Viet Nam
Cameroon	Guyana	Nicaragua	West Bank and Gaza
Cape Verde	Honduras	Niger	Yemen
Central African Republic	India	Nigeria	Zambia
China	Indonesia	Pakistan	Zimbabwe
Comoros	Iran, Islamic Rep	Panama	

APPENDIX B: LIST OF VARIABLES, DEFINITIONS, AND UNITS

B.1. Population Sector Group

Variables used in population sectors of North and South are listed below;

Births: Births (people/year)

ChildMortFrac_Perc: Perceived child mortality measured as probability of death before reaching the age of 15 (unitless)

CMF_Perc_Chg: Change in the perceived level of child mortality ($year^{-1}$)

DeathFrac_PostRepro: Death fraction for post-reproductive stage of population ($year^{-1}$)

DeathFrac_PreRepro: Death fraction for pre-reproductive stage of population ($year^{-1}$)

DeathFrac_Repro: Death fraction for pre-reproductive stage of population ($year^{-1}$)

Deaths_PostRepro: Deaths from the population group at the post-reproductive stage (people/year)

Deaths_PreRepro: Deaths from the population group at the pre-reproductive stage (people/year)

Deaths_Repro: Deaths from the population group at the reproductive stage (people/year)

Fert_Exp: Number of births a woman is expected to have unless a fertility control method is used (people)

Fert_Mult_ChildMort: Effect of child mortality on fertility per woman (unitless)

Fert_Mult_LifeExp: Effect of life expectancy on fertility per woman (unitless)

FertControlEffnesss: Fertility control effectiveness (unitless)

Fertility: Number of births given per woman, throughout her reproductive period (people)

Fertility_Des: Number of births a woman desires to have throughout her reproductive period (people)

HServPerCapita_Index: Index of health service spending made per capita. Base year 1975 (dollars/people)

IncToHealth_Frac_Index: Index value for the fraction of income per capita allocated to health services (unitless)

LabForce: Labor force (people)

LabForce_PartFrac: Labor force participation fraction (unitless)

LifeExp: Average life expectancy at birth (years)

LifeExp_Decr_UrbPol: Fractional decrease in life expectancy due to urban pollution (unitless)

LifeExp_Mult_GlbPol: Effect of global pollution on life expectancy (unitless)

LifeExp_Mult_HServ: Effect of per capita health services on life expectancy (unitless)

LifeExp_Mult_UrbPol: Effect of urban pollution on life expectancy (unitless)

MatFromRepro_Frac: Fraction of people in the reproductive stage that proceed to post-reproductive stage (year^{-1})

MatToRepro_Frac: Fraction of people in the pre-reproductive stage that proceed to reproductive stage (year^{-1})

N_UrbtionFrac: Urbanization fraction. Fraction of rural population who move to urban areas (unitless).

NoOfChild_Des: Desired number of children per woman (people)

NoOfChild_Mult_OPC: Effect of perceived level of economic output per capita on number of children desired (unitless)

OPC_Perc: Perceived level of economic output per capita (dollars/people)

OPC_Perc_Chg: Change in the perceived level of economic output per capita (dollars/people/year)

Pop_PostRepro: Population group at the post-reproductive stage (people)

Pop_PreRepro: Population group at the post-reproductive stage (people)

Pop_Repro: Population group at the post-reproductive stage (people)

PreReproToRepro: Maturation rate from pre-reproductive to reproductive stage (people/year)

Repro_LTime: Length of the reproductive lifetime (year)

ReproToPostRepro: Maturation rate from reproductive to post-reproductive stage (people/year)

RuralPopFrac: Rural population fraction (unitless)

UrbPop_Chg: Change in urban population fraction ($year^{-1}$)

UrbPop_Frac: Urban population fraction (unitless)

UrbtionFrac_Mult_PopDens: Effect of population density on urbanization (unitless)

UrbtionFrac_Mult_UrbEcon: Effect of urban economic life on urbanization (unitless)

B.2. Energy Resources Sector Group

Variables used in energy sectors of North and South are listed below;

Eng_PolImp_Delay: Implementation delay for energy policies (year)

EngCapa_NRen: Non-renewable energy capacity (ktoe/year)

EngCapa_Ren: Renewable energy capacity (ktoe/year)

EngCapa_Ren_Adj: Adjustment desired in the renewable energy capacity ($ktoe/year^2$)

EngCapa_Ren_AdjDelay: Delay experienced in realization of the desired renewable energy capacity (time)

EngCapa_Ren_Depr: Depreciation of renewable energy capacity (ktoe/year^2)

EngCapa_Ren_Des: Desired renewable energy capacity (ktoe/year)

EngCapa_Ren_Inst: Installation of already ordered renewable energy capacity (ktoe/year^2)

EngCapa_Ren_Inst: Installation of new renewable energy capacity (ktoe/year^2)

EngCapa_Ren_InstDelay: Delay experienced in the installation of the renewable energy capacity ordered (year)

EngCapa_Ren_Inv: Investment of new renewable energy capacity (ktoe/year^2)

EngCapa_Ren_Ordered: Stock of ordered renewable energy capacity (ktoe/year)

EngCapa_Ren_Ordered_Des: Desired level of ordered renewable energy capacity (ktoe/year)

EngCapa_Total: Total energy capacity (ktoe/year)

EngDemand_NRen_%Chg: Per cent change in the non-renewable energy demand (unitless)

EngDemand_NRen_Exp: Expected non-renewable energy demand (ktoe/year)

EngDmd_NRen: Demand for non-renewable energy (ktoe/year)

EngDmd_Ren: Demand for renewable energy (ktoe/year)

EngDmd_Ren_Exp: Expected renewable energy demand (ktoe/year)

EngDmd_Ren_Trd: Trend in the renewable energy demand (unitless)

EngDmd_Ren_Trd_Perc: Perceived per cent change in the demand for renewable energy (unitless)

EngDmd_RenFrac: Fraction of renewable energy demand in total energy demand (unitless)

EngDmd_RenFrac_Chg: Change in fraction of renewable energy demand in total energy demand (unitless)

EngDmd_RenFrac_Goal: Target level for fraction of renewable energy demand in total energy demand (unitless)

EngDmd_RenFrac_Goal_GHG: Target level for fraction of renewable energy demand in total energy demand, which is determined by global greenhouses gases accumulation (unitless)

EngDmd_RenFrac_Goal_Scar: Target level for fraction of renewable energy demand in total energy demand, which is determined by non-renewable resource scarcity risk (unitless)

EngDmd_Total: Total energy demand (ktoe/year)

EngPerOutput: Energy required per economic output generated (ktoe/million dollars)

EngShortage_NRen: Shortage experienced in non-renewable energy supply (ktoe/year)

EngShortage_Ren: Shortage experienced in non-renewable energy supply (ktoe/year)

EngSurplus_NRen: Surplus experienced in non-renewable energy supply (ktoe/year)

EngUsage_Frac_Ren: Fraction of renewable energy in total energy usage (unitless)

EngUsage_NRen: Non-renewable energy resources usage (ktoe/year)

EngUsage_Ren: Total renewable energy usage ktoe/year)

EngUsage_Total: Total energy usage from all sources (ktoe/year)

NRen_Scar_Perc: Perceived level of scarcity indicator of non-renewable resources (year)

NRen_Scar_Perc_Chg: Change in the Perceived level of scarcity indicator of non-renewable resources (unitless)

NRen_Scar_Perc_Delay: Delay experienced in the perception of the scarcity indicators of non-renewable resources (year)

NRen_Stock: Stock of non-reewable resources available for energy generation (ktoe)

NRenEng_Imp_Dmd: Demand for non-renewable resources to be imported (ktoe/year)

NRenEng_Imported: Amount of non-renewable resources imported (ktoe/year)

NRenEng_Usage_Delay: Delay experienced in converting the available non-renewable resources to energy (year)

RenEng_Inv: Capital invested in renewable energy generation (million dollar/year)

RenEngInv_Des: Desired renewable energy capacity investment (ktoe/year^2)

RenEngInv_Max: Maximum renewable energy capacity investment that can be realized (ktoe/year^2)

RenEngPerCap: Energy that can be generated from renewable resources, using a single unit of capital (ktoe/Million Dollars.year)

RenEngPerCap_Imp: Improvement in the amount of Energy that can be generated from renewable resources, using a single unit of capital (ktoe/Million Dollars.year^2)

Variables used in energy sectors of RoW are listed below;

R_NRenRes_Discv: Rate of non-renewable resource reserve discoveries (ktoe/year)

R_NRenRes_Dmd_Nfrac: Fractional share of non-renewable resource demand from North in global demand (unitless)

R_NRenRes_Dmd_Sfrac: Fractional share of non-renewable resource demand from South in global demand (unitless)

R_NRenRes_Dmd_Total: Total demand for non-renewable resources (ktoe/year)

R_NRenRes_DmdToProd_Ratio: Ratio of global non-renewable resource demand to production (unitless)

R_NRenRes_FracRem: Remaining fraction of the global non-renewable resource reserves (including discovered and undiscovered) available in 1975 (untiless)

R_NRenRes_Prod: Rate of non-renewable resource production from proven reserves (ktoe/year)

R_NRenRes_ProdCapa: Non-renewable resource production capacity (ktoe/year)

R_NRenRes_Resv: Stock of non-renewable resource reserves (ktoe)

R_NRenRes_ResvToProd_Ratio: Ratio of global non-renewable resource reserves to production (unitless)

R_NRenRes_SuppliedTo_N: Amount of non-renewable resources supplied to North (ktoe/year)

R_NRenRes_SuppliedTo_R: Amount of non-renewable resources supplied to RoW (ktoe/year)

R_NRenRes_SuppliedTo_S: Amount of non-renewable resources supplied to South (ktoe/year)

R_NRenRes_UDResv: Stock of undiscovered non-renewable resource reserves (ktoe)

B.3. Economic Activity Sector Group

Variables used in economic activity sectors of North and South are listed below;

Cap_LifeTime: Average capital lifetime (years)

CapDepr: Capital depreciation (million dollars/year)

CapForHTech: Capital in high technology sector (million dollars)

CapForHTech_Frac: Fraction of total capital dedicated to high technology sector (unitless)

CapForLTech: Capital in low technology sector (million dollars)

CapForLTech_Frac: Fraction of total capital dedicated to low technology sector (unitless)

CapInv: Capital investment (million dollars/year)

Capital: Total capital (million dollars)

CapShift_HtoL: Fractional capital shift from high technology sector to low technology sector (year^{-1})

CapShift_HtoL_Mult_MR: Effect of marginal return on capital shift from high to low technology sector (unitless)

CapShift_HtoL_Mult_Short: Multiplier for capital shift from high to low technology sector due to shortage (unitless)

CapShift_LtoH: Fractional capital shift from low technology sector to high technology sector (year^{-1})

CapShift_LtoH_Mult_MR: Effect of marginal return on capital shift from low to high technology sector (unitless)

CapShift_LtoH_Mult_Short: Multiplier for capital shift from low to high technology sector due to shortage (unitless)

CapTech: Average capital technology index (unitless)

CapTech_New: New capital technology index (unitless)

CapTech_Sprd: New capital technology spreading rate (year^{-1})

CapTechDev: New capital technology development rate (year^{-1})

CapTechDev_Mult_OPC: Effect of output per capita on capital technology development (unitless)

CapUtil_Eng: Capital utilization due to energy (unitless)

Cons_Des: Desired consumption (million dollars)

HTech_Avail: High technology goods available (million dollars)

HTech_Avail_ForInv: High technology goods available for investment (million dollars)

HTech_Des_ForCons: High technology goods desired for consumption (million dollars)

HTech_Des_ForInv: High technology goods desired for consumption (million dollars)

HTech_Dmd: Demand for high technology goods (million dollars)

HTech_DmdToOutput: Demand-to-output ratio for high technology output (unitless)

HTech_EffLab_Mult_Skill: Multiplier for labor effectiveness in high technology sector due to labor skill (unitless)

HTech_LabPerCap: Labor per capital in high technology sector (dollars /people)

HTech_LPC_Index: Index for labor per capital in high technology sector, using 1975 as the base year (unitless)

HTech_MrkShr_N: Share of high technology goods demand of North in global demand (unitless)

HTech_MrkShr_S: Share of high technology goods demand of South in global demand (unitless)

HTech_Output: Total high technology goods output (million dollars)

HTech_Output_Capa: High technology goods output capacity (million dollars)

HTech_RFr_N: High technology goods received from North (million dollars)

HTech_RFr_S: High technology goods received from South (million dollars)

HTech_STo_N: High technology goods sent to North (million dollars)

HTech_STo_R: High technology goods sent to RoW (million dollars)

HTech_STo_S: High technology goods sent to South (million dollars)

HTech_SToN_Frac: Fraction of high technology goods sent to North (unitless)

HTech_SToS_Frac: Fraction of high technology goods sent to South (unitless)

Inv_Des: Desired capital investment (million dollars/year)

Inv_Frac: Fraction of gross output allocated for investment (unitless)

LabForHTech: Labor force in high technology sector (people)

LabForHTech_Eff: Effective labor force in high technology sector (people)

LabForLTech: Labor force in high technology sector (people)

LabForLTech_Eff: Effective labor force in high technology sector (people)

LabSkill_HTech: Labor skill index in high technology sector (unitless)

LabSkill_LTech: Labor skill index in low technology sector (unitless)

LPC_HTech: Labor per capita ratio in high technology sector (people/ dollars)

LPC_LTech: Labor per capita ratio in low technology sector (people/ dollars)

LSHT_Chg: Change in labor skill in high technology sector (year^{-1})

LSHT_Chg_Mult_CurLS: Effect of current level on labor skill change in high technology sector (unitless)

LSHT_Chg_Mult_Prod: Effect of production rate on labor skill change in high technology sector (unitless)

LSLT_Chg: Change in labor skill in low technology sector (year^{-1})

LSLT_Chg_Mult_CurLS: Effect of current level on labor skill change in low technology sector (unitless)

LSLT_Chg_Mult_Prod: Effect of production rate on labor skill change in low technology sector (year^{-1})

LTech_Avail: Total low technology goods available for investment and consumption (million dollars)

LTech_Avail_ForInv: Total low technology goods available for investment (million dollars)

LTech_Des: Total amount of low technology goods desired (million dollars)

LTech_Des_ForCons: Total amount of low technology goods desired for consumption (million dollars)

LTech_Des_ForInv: Total amount of low technology goods desired for investment (million dollars)

LTech_Dmd: Demand for low technology goods (million dollars)

LTech_DmdToOutput: Demand-to-output ratio for high technology output (unitless)

LTech_LabPerCap: Labor per capital in low technology sector (dollars /people)

LTech_LPC_Index: Index for labor per capital in high technology sector, using 1975 as the base year (unitless)

LTech_MrkShr_N: Share of low technology goods demand of North in global demand (unitless)

LTech_MrkShr_S: Share of low technology goods demand of South in global demand (unitless)

LTech_Output: Total low technology goods output (million dollars)

LTech_Output_Capa: High technology goods output capacity (million dollars)

LTech_RFr_N: Low technology goods received from North (million dollars)

LTech_RFr_S: Low technology goods received from South (million dollars)

LTech_STo_N: Low technology goods sent to North (million dollars)

LTech_STo_R: Low technology goods sent to RoW (million dollars)

LTech_STo_S: Low technology goods sent to South (million dollars)

LTech_SToN_Frac: Fraction of low technology goods sent to North (unitless)

LTech_SToS_Frac: Fraction of low technology goods sent to South (unitless)

LTechFrac_ForCons: Share of low technology goods in total consumption (unitless)

LTechFrac_ForInv: Share of low technology goods in total investment (unitless)

MargRet_HtoL: Marginal return in productivity, obtained by shifting capital from high to low technology sector (million dollars/year)

MargRet_LtoH: Marginal return in productivity, obtained by shifting capital from low to high technology sector (million dollars/year)

MrkIntg_Coef: Global market integration coefficient (unitless)

OPC_Index: Index for output per capita, base year 1975 (unitless)

Output: Gross output (million dollars)

Output_Frac_ForEng: Fraction of output exchanged for energy resources (unitless)

Output_STo_R: Output sent to RoW (million dollars)

OutputCapa_Cap: Output capacity of the available capital (million dollars/year)

OutputCapa_Eng: Output capacity that can be attained using the available energy capacity (million dollars/year)

OutputPerCapita: Gross output divided by population (dollars /people)

Pvity_HTech: Capital productivity in high technology sector ($year^{-1}$)

Pvity_LTech: Capital productivity in low technology sector ($year^{-1}$)

Pvity_LTech: Productivity in low technology sector ($year^{-1}$)

PvityHTech_Mult_CT: Effect of capital technology on capital productivity in high technology sector (unitless)

PvityHTech_Mult_LPC: Effect of labor-per-capital ratio on capital productivity in high technology sector (unitless)

PvityLTech_Mult_CT: Effect of capital technology on capital productivity in low technology sector (unitless)

PvityLTech_Mult_LPC: Effect of labor-per-capital ratio on capital productivity in low technology sector (unitless)

B.4. Pollution Sector

Co2_AssimFrac_Mult_SinkCapa: Effect of sink capacity on fraction of atmospheric CO_2 assimilated (unitless).

Co2_Atm: Level of accumulated greenhouse gases in the atmosphere (GtC)

Co2_Atm_Assim: Rate of CO_2 assimilation from the atmosphere (GtC/year).

Co2_Atm_Assim_Frac: Fraction of atmospheric CO_2 assimilated in a year ($year^{-1}$)

Co2_Atm_Index_Perc: Perceived atmospheric CO_2 level index (base year 1975) (unitless).

Co2_AtmPPM: Level of accumulated greenhouse gases in the atmosphere (ppm)

Co2_AtmSink_ConcDisc: Concentration discrepancy of CO_2 between global sinks and atmosphere (unitless)

Co2_Index_Perc_Delay: Delay experienced in the perception of the atmospheric CO_2 level (years)

Co2_Sink: Accumulated CO_2 amount in the global sinks (GtC)

Co2_Sink_Assim: Rate of CO_2 assimilation from the global sinks (GtC/year)

Co2_Sink_Assim_Delay: Delay experienced in the assimilation of CO_2 at the global sinks (years)

Co2IP_Chg: Change in the perceived level of atmospheric CO_2 index ($year^{-1}$)

N_Co2_Ems: CO_2 emissions caused by North block (GtC/year)

R_Co2_Ems: CO_2 emissions caused by RoW block (GtC/year)

S_Co2_Ems: CO_2 emissions caused by South block (GtC/year)

APPENDIX C: EQUATIONS OF THE MODEL

R_Capital(t) = R_Capital(t - dt) + (R_CapChg) * dt

INIT R_Capital = R_Capital_Ini

R_CapChg = R_Capital*R_Cap_GrowthFrac

R_Population(t) = R_Population(t - dt) + (R_PopChg) * dt

INIT R_Population = 720

R_PopChg = R_Population*R_Pop_GrowthFrac

G_Population = R_Population+N_Population+S_Population

N_AvgPvity = N_Output/N_Capital

N_Capital_Old = DELAY(N_Capital,1)

N_Cap_GrowthFrac = (N_Capital-N_Capital_Old)/N_Capital_Old

N_Pop_GrowthFrac = (N_Population-N_Pop_Old)/N_Pop_Old

N_Pop_Old = DELAY(N_Population,1)

R_AvgPvity = R_Economy_Weight_N*N_AvgPvity+(1-R_Economy_Weight_N)*S_AvgPvity

R_Capital_Ini = N_Capital_Ini*R_Economy_Weight_N+S_Capital_Ini*(1-R_Economy_Weight_N)

R_Cap_GrowthFrac = N_Cap_GrowthFrac*R_Economy_Weight_N+(1-R_Economy_Weight_N)*S_Cap_GrowthFrac

R_Co2_Ems1 = R_NRenRes_Usage*R_GHG_Per_NRen1

R_Economy_Weight_N = 0.6

R_Energy_Weight_N = 0.6

R_EngDmd_NRen = R_Output*R_EngPerOutput*(1-R_EngUsage_Frac_Ren)

R_EngPerOutput = N_EngPerOutput*R_Energy_Weight_N+S_EngPerOutput*(1-R_Energy_Weight_N)

R_EngUsage_Frac_Ren = N_EngUsage_Frac_Ren*R_Energy_Weight_N+S_EngUsage_Frac_Ren*(1-R_Energy_Weight_N)

R_GHG_Per_NRen1 = N_Co2_Per_NRen*R_GHG_Weight_N+S_Co2_Per_NRen*(1-R_GHG_Weight_N)

R_GHG_Weight_N = 0.6

R_NRenRes_Imp_Dmd1 = R_EngDmd_NRen

R_Output = R_Capital*R_AvgPvity

R_PopGrowthFrac = (R_Population_Real-R_Pop_Old)/R_Pop_Old

```
R_Pop_GrowthFrac = N_Pop_GrowthFrac*R_Pop_Weight_N+(1-
R_Pop_Weight_N)*S_Pop_GrowthFrac
R_Pop_Old = delay(R_Population_Real,dt)
R_Pop_Weight_N = 0.6
S_AvgPvity = S_Output/S_Capital
S_Capital_Old = DELAY(S_Capital,1)
S_Cap_GrowthFrac = (S_Capital-S_Capital_Old)/S_Capital_Old
S_Pop_GrowthFrac = (S_Population-S_Pop_Old)/S_Pop_Old
S_Pop_Old = DELAY(S_Population,1)
R_NRenResUsage_Real = GRAPH(time)
(1975, 669306), (1980, 842310), (1985, 894008), (1990, 958096), (1995, 1.7e+006), (2000,
1.7e+006)
R_Output_Real = GRAPH(time)
(1975, 1.8e+006), (1980, 3.3e+006), (1985, 4.2e+006), (1990, 5.9e+006), (1995, 7.1e+006), (2000,
8.7e+006)
R_Population_Real = GRAPH(time)
(1975, 714), (1980, 776), (1985, 838), (1990, 897), (1995, 947), (2000, 992)
G_Co2_Atm(t) = G_Co2_Atm(t - dt) + (R_Co2_Ems + N_Co2_Ems + S_Co2_Ems -
G_Co2_OceanUptake) * dt
INIT G_Co2_Atm = G_Co2_Atm_Ini
R_Co2_Ems = if Key_R_Endo=0 then R_Co2_Per_NRen*R_NRenRes_Usage/1000000 else
R_Co2_Ems1/1000000
N_Co2_Ems = N_Co2_Per_NRen*N_NRenRes_Usage/1000000
S_Co2_Ems = S_Co2_Per_NRen*S_NRenRes_Usage/1000000
G_Co2_OceanUptake = G_Co2_ConcDif*G_Co2_OcUpt_Frac*G_Co2_Atm_VolIndex
G_Co2_Atm_Index_Perc(t) = G_Co2_Atm_Index_Perc(t - dt) + (G_Co2IP_Chg) * dt
INIT G_Co2_Atm_Index_Perc = 0.9
G_Co2IP_Chg = (G_Co2_Atm_Index-G_Co2_Atm_Index_Perc)/G_Co2_Index_Perc_Delay
G_Co2_Ocean(t) = G_Co2_Ocean(t - dt) + (G_Co2_OceanUptake - G_Co2_OcDiffToDeep) * dt
INIT G_Co2_Ocean = G_Co2_Ocean_Ini
G_Co2_OceanUptake = G_Co2_ConcDif*G_Co2_OcUpt_Frac*G_Co2_Atm_VolIndex
G_Co2_OcDiffToDeep = G_Co2_Ocean/G_Co2_OcDiffToDeep_Delay
G_Co2_AtmConc_PPM = G_Co2_Atm/2.13
G_Co2_Atm_Index = G_Co2_Atm/G_Co2_Atm_Ini
G_Co2_Atm_Ini = 706
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G_Co2_Atm_VolIndex = 6
G_Co2_ConcDif =
(G_Co2_Atm/G_Co2_Atm_VolIndex)/(G_Co2_Ocean/G_Co2_Ocean_VolIndex)
G_Co2_Index_Perc_Delay = 5
G_Co2_OcDiffToDeep_Delay = 600
G_Co2_Ocean_Ini = 1030
G_Co2_Ocean_VolIndex = 10
G_Co2_OcUpt_Frac = G_Co2_OcUpt_Frac_Norm*G_Co2_OcUptk_Frac_Mult_Capa
G_Co2_OcUpt_Frac_Norm = 0.3
Key_R_Endo = 0
R_Co2_Ems_Real = R_Co2_Ems_Real2/1000000
G_Co2_AtmConc_PPM_Real = GRAPH(time)
(1975, 331), (1980, 339), (1985, 346), (1990, 354), (1995, 361), (2000, 369)
G_Co2_OcUptk_Frac_Mult_Capa = GRAPH(G_Co2_Ocean/G_Co2_Ocean_Ini)
(1.00, 1.00), (1.02, 0.98), (1.04, 0.963), (1.06, 0.94), (1.08, 0.912), (1.10, 0.878), (1.12, 0.843),
(1.14, 0.797), (1.16, 0.75), (1.18, 0.695), (1.20, 0.635)
N_Co2_Ems_Real = GRAPH(time)
(1975, 2.24), (1980, 2.43), (1985, 2.30), (1990, 2.51), (1995, 2.68), (2000, 2.73)
N_Co2_Per_NRen = GRAPH(time)
(1975, 0.75), (1980, 0.75), (1985, 0.75), (1990, 0.75), (1995, 0.75), (2000, 0.75), (2005, 0.75),
(2010, 0.75), (2015, 0.75), (2020, 0.75)
N_EngDmd_RenFrac_GoalCo2 = GRAPH(G_Co2_Atm_Index_Perc)
(1.00, 0.06), (1.10, 0.09), (1.20, 0.155), (1.30, 0.23), (1.40, 0.325), (1.50, 0.445), (1.60, 0.585),
(1.70, 0.74), (1.80, 0.995), (1.90, 1.00), (2.00, 1.00)
R_Co2_Ems_Real2 = GRAPH(time)
(1975, 768526), (1980, 964168), (1985, 1e+006), (1990, 1.1e+006), (1995, 1.4e+006), (2000,
1.4e+006)
R_Co2_Per_NRen = GRAPH(time)
(1975, 1.14), (1980, 1.11), (1985, 1.05), (1990, 0.987), (1995, 0.915), (2000, 0.852), (2005, 0.818),
(2010, 0.785), (2015, 0.765), (2020, 0.755)
S_Co2_Ems_Real = GRAPH(time)
(1975, 0.566), (1980, 0.738), (1985, 0.955), (1990, 1.21), (1995, 1.61), (2000, 1.58)
S_Co2_Per_NRen = GRAPH(time)
(1975, 1.04), (1980, 1.04), (1985, 1.02), (1990, 0.984), (1995, 0.93), (2000, 0.86), (2005, 0.82),
(2010, 0.788), (2015, 0.762), (2020, 0.752)
```

S_EngDmd_RenFrac_GoalCo2 = GRAPH(G_Co2_Atm_Index_Perc)
(1.00, 0.06), (1.10, 0.09), (1.20, 0.155), (1.30, 0.23), (1.40, 0.325), (1.50, 0.445), (1.60, 0.585), (1.70, 0.74), (1.80, 0.995), (1.90, 1.00), (2.00, 1.00)

G_Dmd = G_HTech_Dmd+G_LTech_Dmd

G_HTech_Dmd = N_HTech_Des+S_HTech_Des

G_HTech_DmdToOutput = G_HTech_Dmd/G_HTech_Output_Net

G_HTech_Output_Net = N_HTech_Output_Net+S_HTech_Output_Net

G_LTech_Dmd = N_LTech_Des+S_LTech_Des

G_LTech_DmdToOutput = G_LTech_Dmd/G_LTech_Output_Net

G_LTech_Output_Net = N_LTech_Output_Net+S_LTech_Output_Net

G_Output_Net = G_HTech_Output_Net+G_LTech_Output_Net

G_Pvity_LTech =
(N_LTech_Output*N_Pvity_LTech+S_LTech_Output*S_Pvity_LTech)/(N_LTech_Output+S_LTech_Output)

N_ExpTo_S = N_HTech_STo_S+N_LTech_STo_S

N_GHTechSupFrac = N_HTech_Output_Net/G_HTech_Output_Net

N_GLTechSupFrac = N_LTech_Output_Net/G_LTech_Output_Net

N_HTech_DmdToOutput = N_HTech_Mrk/N_HTech_SupToMrkFrAll

N_HTech_Dmd_MrkShr = N_HTech_Des/G_HTech_Dmd

N_HTech_Mrk = N_HTech_Mrk_N+N_HTech_Mrk_S

N_HTech_MrkFrac_Common = (N_HTech_Mrk_S+S_HTech_Mrk_N)/N_HTech_Mrk

N_HTech_MrkShrOf_N = N_HTech_Mrk_N/N_HTech_Mrk

N_HTech_MrkShrOf_S = N_HTech_Mrk_S/N_HTech_Mrk

N_HTech_Mrk_N = N_HTech_Des

N_HTech_Mrk_S = S_HTech_Des*N_MrkIntg_Coef

N_HTech_Output_Net = N_HTech_Output*(1-N_Output_Frac_ForEng)

N_HTech_RFr_N = N_HTech_STo_N

N_HTech_RFr_S = S_HTech_STo_N

N_HTech_SToN_Frac = N_HTech_MrkShrOf_N+(N_HTech_MrkShrOf_S-N_HTech_SToS_Frac)

N_HTech_SToS_Frac = N_HTech_MrkShrOf_S*S_ImpRedcMult

N_HTech_STo_N = N_HTech_Output_Net*N_HTech_SToN_Frac

N_HTech_STo_R = N_HTech_Output*N_Output_Frac_ForEng

N_HTech_STo_S = N_HTech_Output_Net*N_HTech_SToS_Frac

N_HTech_SupToMrkFrAll = N_HTech_Output_Net+S_HTech_Output_Net*(S_HTech_MrkFrac_Common)

N_ImpFr_S = S_ExpTo_N

N_LTech_DmdToOutput = N_LTech_Mrk/N_LTech_SupToMrkFrAll

N_LTech_Dmd_MrkShr = N_LTech_Des/G_LTech_Dmd

N_LTech_Mrk = N_LTech_Mrk_N+N_LTech_Mrk_S

N_LTech_MrkFrac_Common = (N_LTech_Mrk_S+S_LTech_Mrk_N)/N_LTech_Mrk

N_LTech_MrkShrOf_N = N_LTech_Mrk_N/N_LTech_Mrk

N_LTech_MrkShrOf_S = N_LTech_Mrk_S/N_LTech_Mrk

N_LTech_Mrk_N = N_LTech_Des

N_LTech_Mrk_S = S_LTech_Des*N_MrkIntg_Coef

N_LTech_Output_Net = N_LTech_Output*(1-N_Output_Frac_ForEng)

N_LTech_RFr_N = N_LTech_STo_N

N_LTech_RFr_S = S_LTech_STo_N

N_LTech_SToN_Frac = N_LTech_MrkShrOf_N+(N_LTech_MrkShrOf_S-N_LTech_SToS_Frac)

N_LTech_SToS_Frac = N_LTech_MrkShrOf_S*S_ImpRedcMult

N_LTech_STo_N = N_LTech_Output_Net*N_LTech_SToN_Frac

N_LTech_STo_R = N_LTech_Output*N_Output_Frac_ForEng

N_LTech_STo_S = N_LTech_Output_Net*N_LTech_SToS_Frac

N_LTech_SupToMrkFrAll = N_LTech_Output_Net+S_LTech_Output_Net*S_LTech_MrkFrac_Common

N_MrkIntg_Coef = 1

N_Output_Frac_ForEng = N_Output_STo_R/N_Output

N_Output_STo_R = N_NRenRes_Import/G_OutputToNRen_VIndex

S_ExpTo_N = S_HTech_STo_N+S_LTech_STo_N

S_HTech_Des_MrkShr = S_HTech_Des/G_HTech_Dmd

S_HTech_DmdToOutput = S_HTech_Mrk/S_HTech_SupToMrkFrAll

S_HTech_Mrk = S_HTech_Mrk_N+S_HTech_Mrk_S

S_HTech_MrkFrac_Common = (N_HTech_Mrk_S+S_HTech_Mrk_N)/S_HTech_Mrk

S_HTech_MrkShrOf_N = S_HTech_Mrk_N/S_HTech_Mrk

S_HTech_MrkShrOf_S = S_HTech_Mrk_S/S_HTech_Mrk

S_HTech_Mrk_N = N_HTech_Des*S_MrkIntg_Coef

S_HTech_Mrk_S = S_HTech_Des

S_HTech_Output_Net = S_HTech_Output*(1-S_Output_Frac_ForEng)

S_HTech_RFr_N = N_HTech_STo_S

S_HTech_RFr_S = S_HTech_STo_S

S_HTech_SToN_Frac = S_HTech_MrkShrOf_N*S_Exp_Mult_ForExcDef

S_HTech_SToS_Frac = S_HTech_MrkShrOf_S-(S_HTech_SToN_Frac-S_HTech_MrkShrOf_N)

S_HTech_STo_N = S_HTech_Output_Net*S_HTech_SToN_Frac

S_HTech_STo_R = S_HTech_Output*S_Output_Frac_ForEng

S_HTech_STo_S = S_HTech_Output_Net*S_HTech_SToS_Frac

S_HTech_SupToMrkFrAll = S_HTech_Output_Net+N_HTech_Output_Net*(N_HTech_MrkFrac_Common)

S_ImpFr_N = N_ExpTo_S

S_LTech_DmdToOutput = S_LTech_Mrk/S_LTech_SupToMrkFrAll

S_LTech_Dmd_MrkShr = S_LTech_Des/G_LTech_Dmd

S_LTech_Mrk = S_LTech_Mrk_N+S_LTech_Mrk_S

S_LTech_MrkFrac_Common = (N_LTech_Mrk_S+S_LTech_Mrk_N)/S_LTech_Mrk

S_LTech_MrkShrOf_N = S_LTech_Mrk_N/S_LTech_Mrk

S_LTech_MrkShrOf_S = S_LTech_Mrk_S/S_LTech_Mrk

S_LTech_Mrk_N = N_LTech_Des*S_MrkIntg_Coef

S_LTech_Mrk_S = S_LTech_Des

S_LTech_Output_Net = S_LTech_Output*(1-S_Output_Frac_ForEng)

S_LTech_RFr_N = N_LTech_STo_S

S_LTech_RFr_S = S_LTech_STo_S

S_LTech_SToN_Frac = S_LTech_MrkShrOf_N*S_Exp_Mult_ForExcDef

S_LTech_SToS_Frac = S_LTech_MrkShrOf_S-(S_LTech_SToN_Frac-S_LTech_MrkShrOf_N)

S_LTech_STo_N = S_LTech_Output_Net*S_LTech_SToN_Frac

S_LTech_STo_R = S_LTech_Output*S_Output_Frac_ForEng

S_LTech_STo_S = S_LTech_Output_Net*S_LTech_SToS_Frac

S_LTech_SupToMrkFrAll = S_LTech_Output_Net+N_LTech_Output_Net*N_LTech_MrkFrac_Common

S_MrkIntg_Coef = 1

S_Output_Frac_ForEng = S_Output_STo_R/S_Output

S_Output_STo_R = S_NRenRes_Import/G_OutputToNRen_VIndex

S_ImpRedcMult = GRAPH(time)

(1975, 1.00), (1983, 1.00), (1990, 1.00), (1998, 1.00), (2005, 1.00), (2013, 1.00), (2020, 1.00), (2028, 1.00), (2035, 1.00), (2043, 1.00), (2050, 1.00)

N_CapForHTech_Frac(t) = N_CapForHTech_Frac(t - dt) + (N_CapShift_LtoH - N_CapShift_HtoL) * dt

INIT N_CapForHTech_Frac = 1-N_CapForLTech_Frac

N_CapShift_LtoH =

N_CapShift_Nrm*N_CapShift_LtoH_Mult_Short*N_CapShft_LtoH_Mult_Limit*N_CapShift_LtoH_Mult_MR

N_CapShift_HtoL =

N_CapShift_Nrm*N_CapShift_HtoL_Mult_Short*N_CapShift_HtoL_Mult_Limit*N_CapShift_HtoL_Mult_MR

N_CapForLTech_Frac(t) = N_CapForLTech_Frac(t - dt) + (N_CapShift_HtoL - N_CapShift_LtoH) * dt

INIT N_CapForLTech_Frac = N_CapForLTech_Frac_Ini

N_CapShift_HtoL =

N_CapShift_Nrm*N_CapShift_HtoL_Mult_Short*N_CapShift_HtoL_Mult_Limit*N_CapShift_HtoL_Mult_MR

N_CapShift_LtoH =

N_CapShift_Nrm*N_CapShift_LtoH_Mult_Short*N_CapShft_LtoH_Mult_Limit*N_CapShift_LtoH_Mult_MR

N_Capital(t) = N_Capital(t - dt) + (N_CapInv - N_CapDepr) * dt

INIT N_Capital = N_Capital_Ini

N_CapInv = N_Inv-N_RenEng_Inv

N_CapDepr = N_Capital/Cap_LifeTime

N_CapTech(t) = N_CapTech(t - dt) + (N_CapTechDiff) * dt

INIT N_CapTech = N_CapTech_Ini

N_CapTechDiff = (N_CapTech_New-N_CapTech)/N_TechSprd_Delay

N_CapTech_New(t) = N_CapTech_New(t - dt) + (N_CapTechDev) * dt

INIT N_CapTech_New = N_CapTech_New_Ini

N_CapTechDev = N_CapTechDev_Norm*N_CapTechDev_Mult_OPC

N_LabSkill_HTech(t) = N_LabSkill_HTech(t - dt) + (N_LSHT_Chg) * dt

INIT N_LabSkill_HTech = N_LabSkill_HTech_Ini

N_LSHT_Chg = N_LSHT_Chg_Norm*N_LSHT_Chg_Mult_Prod*N_LSHT_Chg_Mult_CurLS

N_LabSkill_LTech(t) = N_LabSkill_LTech(t - dt) + (N_LSLT_Chg) * dt

INIT N_LabSkill_LTech = N_LabSkill_LTech_Ini

N_LSLT_Chg = N_LSLT_Chg_Norm*N_LSLT_Chg_Mult_Prod*N_LSLT_Chg_Mult_CurLS

Cap_LifeTime = 25

Key = 0

N_CapForHTech = N_Capital*(1-N_CapForLTech_Frac)

N_CapForLTech = N_Capital*N_CapForLTech_Frac

N_CapForLTech_Frac_Ini = 0.4

N_Capital_Ini = 14000000

N_CapShift_HtoL_Mult_Short = MAX(0,N_LTech_DmdToOutput-1)

N_CapShift_LtoH_Mult_Short = MAX(0,N_HTech_DmdToOutput-1)

N_CapShift_Nrm = 0.5

N_CapTechDev_Norm = 0.02

N_CapTech_Avg = N_CapTech

N_CapTech_Ini = 3

N_CapTech_New_Ini = 5

N_CapUtil_Eng = MIN(1,N_OutputCapa_Eng/N_OutputCapa_Cap)

N_Cons_Des = N_Output_Net*(1-N_Inv_Frac)

N_HTech_Avail = N_HTech_STo_N+S_HTech_STo_N

N_HTech_Avail_ForInv = N_HTech_Avail*N_HTech_InvFracInDmd

N_HTech_Des = N_HTech_Des_ForCons+N_HTech_Des_ForInv

N_HTech_DesToAvail = N_HTech_Des/N_HTech_Avail

N_HTech_Des_ForCons = N_Cons_Des*(1-N_LTechFrac_ForCons)

N_HTech_Des_ForInv = N_Inv_Des*(1-N_LTechFrac_ForInv)

N_HTech_EffLab_Mult_Skill = N_LabSkill_HTech/INIT(N_LabSkill_HTech)

N_HTech_InvFracInDmd = N_HTech_Des_ForInv/N_HTech_Des

N_HTech_LabPerCap = N_LabForHTech_Eff/N_CapForHTech

N_HTech_LPC_Index = N_HTech_LabPerCap/INIT(N_HTech_LabPerCap)

N_HTech_Output = N_CapUtil_Eng*N_HTech_Output_Capa

N_HTech_Output_Capa = N_CapForHTech*N_Pvity_HTech

N_Inv = MIN(N_Inv_Max_HTech,N_Inv_Max_LTech)

N_Inv_Des = N_Inv_Frac*N_Output_Net

N_Inv_Frac = 0.25

N_Inv_Max_HTech = N_HTech_Avail_ForInv/(1-N_LTechFrac_ForInv)

N_Inv_Max_LTech = N_LTech_Avail_ForInv/N_LTechFrac_ForInv

N_LabForHTech = N_LabForce*(1-N_LabForLTech_Frac)

N_LabForHTech_Eff = N_LabForHTech*N_HTech_EffLab_Mult_Skill

N_LabForLTech = N_LabForLTech_Frac*N_LabForce

N_LabForLTech_Eff = N_LabForLTech*N_LTech_EffLab_Mult_Skill

N_LabForLTech_Frac = N_CapForLTech_Frac

N_LabSkill_HTech_Ini = 1

N_LabSkill_LTech_Ini = 2

N_LSHT_Chg_Mult_Prod = N_OutputPerLab_HTech/INIT(N_OutputPerLab_HTech)

N_LSHT_Chg_Norm = 0.005

N_LSLT_Chg_Mult_Prod = N_OutputPerLab_LTech/INIT(N_OutputPerLab_LTech)

N_LSLT_Chg_Norm = 0.05

N_LTechFrac_ForCons = N_LTechFrac_ForCons_Ini*N_LTForCons_Mult_OPC

N_LTechFrac_ForCons_Ini = 0.4

N_LTechFrac_ForInv = N_LTechFrac_ForInv_Ini*N_LTForInv_Mult_OPC

N_LTechFrac_ForInv_Ini = 0.3

N_LTech_Avail = N_LTech_STo_N+S_LTech_STo_N

N_LTech_Avail_ForInv = N_LTech_Avail*N_LTech_InvFracInDmd

N_LTech_Des = N_LTech_Des_ForCons+N_LTech_Des_ForInv

N_LTech_DesToAvail = N_LTech_Des/N_LTech_Avail

N_LTech_Des_ForCons = N_Cons_Des*N_LTechFrac_ForCons

N_LTech_Des_ForInv = N_Inv_Des*N_LTechFrac_ForInv

N_LTech_EffLab_Mult_Skill = N_LabSkill_LTech/INIT(N_LabSkill_LTech)

N_LTech_InvFracInDmd = N_LTech_Des_ForInv/N_LTech_Des

N_LTech_LabPerCap = N_LabForLTech_Eff/N_CapForLTech

N_LTech_LPC_Index = N_LTech_LabPerCap/INIT(N_LTech_LabPerCap)

N_LTech_Output = N_LTech_Output_Capa*N_CapUtil_Eng

N_LTech_Output_Capa = N_CapForLTech*N_Pvity_LTech

N_MargRet_HtoL = N_Pvity_LTech-N_Pvity_HTech

N_MargRet_LtoH = N_Pvity_HTech-N_Pvity_LTech

N_OPC_Index = N_OutputPerCapita/INIT(N_OutputPerCapita)

N_Output = N_HTech_Output+N_LTech_Output

N_OutputCapa_Cap = N_HTech_Output_Capa+N_LTech_Output_Capa

N_OutputCapa_Eng = N_EngCapa_Total/N_EngPerOutput

N_OutputPerCapita = N_Output_Net/N_Population

N_OutputPerLab_HTech = N_HTech_Output/N_LabForHTech

N_OutputPerLab_LTech = N_LTech_Output/N_LabForLTech

N_Output_Net = N_Output*(1-N_Output_Frac_ForEng)

N_PvityHTech_Norm = 0.5

N_PvityLTech_Norm = 0.3

N_Pvity_HTech = if key=1 then
N_PvityHTech_Norm*N_PvityHTech_Mult_LPC*N_PvityHTech_Mult_CT else
N_Pvity_HTech_Test

N_Pvity_HTech_Test = 0.4

N_Pvity_LTech = if key=1 then
N_PvityLTech_Norm*N_PvityLTech_Mult_CT*N_PvityLTech_Mult_LPC else
N_Pvity_LTech_Test

N_Pvity_LTech_Test = 0.4

N_TechSprd_Delay = 10

Relative_OPC_NtoS = N_OutputPerCapita/S_OutputPerCapita

N_CapShft_LtoH_Mult_Limit = GRAPH(N_CapForLTech_Frac)
(0.00, 0.00), (0.01, 0.44), (0.02, 0.785), (0.03, 0.91), (0.04, 0.97), (0.05, 0.995), (0.06, 1.00), (0.07, 1.00), (0.08, 1.00), (0.09, 1.00), (0.1, 1.00)

N_CapShift_HtoL_Mult_Limit = GRAPH(N_CapForHTech_Frac)
(0.00, 0.00), (0.01, 0.44), (0.02, 0.785), (0.03, 0.91), (0.04, 0.97), (0.05, 0.995), (0.06, 1.00), (0.07, 1.00), (0.08, 1.00), (0.09, 1.00), (0.1, 1.00)

N_CapShift_HtoL_Mult_MR = GRAPH(N_MargRet_HtoL)
(-1.00, 0.00), (-0.8, 0.04), (-0.6, 0.13), (-0.4, 0.3), (-0.2, 0.6), (-5.55e-017, 1.00), (0.2, 1.29), (0.4, 1.51), (0.6, 1.68), (0.8, 1.80), (1.00, 1.86)

N_CapShift_LtoH_Mult_MR = GRAPH(N_MargRet_LtoH)
(-1.00, 0.00), (-0.8, 0.04), (-0.6, 0.13), (-0.4, 0.3), (-0.2, 0.6), (-5.55e-017, 1.00), (0.2, 1.29), (0.4, 1.51), (0.6, 1.68), (0.8, 1.80), (1.00, 1.86)

N_CapTechDev_Mult_OPC = GRAPH(N_OPC_Index)
(0.00, 1.00), (2.00, 2.05), (4.00, 2.95), (6.00, 3.75), (8.00, 4.40), (10.0, 4.85), (12.0, 5.10), (14.0, 5.25), (16.0, 5.40), (18.0, 5.45), (20.0, 5.55)

N_LSHT_Chg_Mult_CurLS = GRAPH(N_LabSkill_HTech/INIT(N_LabSkill_HTech))
(1.00, 1.00), (1.40, 0.805), (1.80, 0.6), (2.20, 0.435), (2.60, 0.3), (3.00, 0.19), (3.40, 0.115), (3.80, 0.075), (4.20, 0.04), (4.60, 0.015), (5.00, 0.005)

N_LSLT_Chg_Mult_CurLS = GRAPH(N_LabSkill_LTech/INIT(N_LabSkill_LTech))
(1.00, 1.00), (1.40, 0.805), (1.80, 0.6), (2.20, 0.435), (2.60, 0.3), (3.00, 0.19), (3.40, 0.115), (3.80, 0.075), (4.20, 0.04), (4.60, 0.015), (5.00, 0.005)

N_LTForCons_Mult_OPC = GRAPH(N_OPC_Index)
(0.00, 1.13), (1.00, 1.00), (2.00, 0.912), (3.00, 0.846), (4.00, 0.798), (5.00, 0.75), (6.00, 0.714), (7.00, 0.684), (8.00, 0.666), (9.00, 0.654), (10.0, 0.642)

N_LTForInv_Mult_OPC = GRAPH(N_OPC_Index)

(0.00, 1.13), (1.00, 1.00), (2.00, 0.894), (3.00, 0.804), (4.00, 0.726), (5.00, 0.666), (6.00, 0.624), (7.00, 0.594), (8.00, 0.576), (9.00, 0.564), (10.0, 0.558)

N_Output_Real = GRAPH(time)

(1975, 4.4e+006), (1980, 7.3e+006), (1985, 9.7e+006), (1990, 1.4e+007), (1995, 1.8e+007), (2000, 2.2e+007)

N_PvityHTech_Mult_CT = GRAPH(N_CapTech_Avg/INIT(N_CapTech_Avg))

(0.00, 0.15), (1.00, 0.585), (2.00, 1.00), (3.00, 1.50), (4.00, 1.92), (5.00, 2.26), (6.00, 2.58), (7.00, 2.86), (8.00, 3.10), (9.00, 3.32), (10.0, 3.50)

N_PvityHTech_Mult_LPC = GRAPH(N_HTech_LPC_Index)

(0.00, 0.00), (0.5, 0.36), (1.00, 0.63), (1.50, 0.85), (2.00, 1.00), (2.50, 1.11), (3.00, 1.20), (3.50, 1.27), (4.00, 1.31), (4.50, 1.34), (5.00, 1.35)

N_PvityLTech_Mult_CT = GRAPH(N_CapTech_Avg/INIT(N_CapTech_Avg))

(0.00, 1.00), (1.00, 1.26), (2.00, 1.49), (3.00, 1.68), (4.00, 1.86), (5.00, 2.00), (6.00, 2.12), (7.00, 2.19), (8.00, 2.25), (9.00, 2.30), (10.0, 2.33)

N_PvityLTech_Mult_LPC = GRAPH(N_LTech_LPC_Index)

(0.00, 0.3), (0.556, 0.56), (1.11, 0.8), (1.67, 1.00), (2.22, 1.16), (2.78, 1.26), (3.33, 1.31), (3.89, 1.34), (4.44, 1.37), (5.00, 1.37)

N_EngCapa_Ren(t) = N_EngCapa_Ren(t - dt) + (N_EngCapa_Ren_Inst - N_EngCapa_Ren_Dep) * dt

INIT N_EngCapa_Ren = N_EngDmd_Total*0.02

N_EngCapa_Ren_Inst = N_EngCapa_Ren_Ordered/N_EngCapa_Ren_InstDelay

N_EngCapa_Ren_Dep = N_EngCapa_Ren/Cap_Lifetime

N_EngCapa_Ren_Ordered(t) = N_EngCapa_Ren_Ordered(t - dt) + (N_EngCapa_Ren_Inv - N_EngCapa_Ren_Inst) * dt

INIT N_EngCapa_Ren_Ordered = N_EngCapa_Ren_Adj*N_EngCapa_Ren_InstDelay

N_EngCapa_Ren_Inv = MIN(N_RenEngInv_Des,N_EngCapa_Ren_Inv_Max)

N_EngCapa_Ren_Inst = N_EngCapa_Ren_Ordered/N_EngCapa_Ren_InstDelay

N_EngDmd_RenFrac(t) = N_EngDmd_RenFrac(t - dt) + (N_EngDmd_RenFrac_Chg) * dt

INIT N_EngDmd_RenFrac = N_EngDmd_RenFrac_Ini

N_EngDmd_RenFrac_Chg = (N_EngDmd_RenFrac_Goal-N_EngDmd_RenFrac)/(N_Eng_PolImp_Delay/N_EngDmd_RenFrac_Mult_Tech)

N_EngDmd_Ren_%Chg_Perc(t) = N_EngDmd_Ren_%Chg_Perc(t - dt) + (N_EDR_%Chg_PercChg) * dt

INIT N_EngDmd_Ren_%Chg_Perc = N_EngDmd_Ren_%Chg+0.02

N_EDR_%Chg_PercChg = (N_EngDmd_Ren_%Chg-N_EngDmd_Ren_%Chg_Perc)/N_EngDmd_%Chg_PercDelay

N_NRenRes_Stock(t) = N_NRenRes_Stock(t - dt) + (N_NRenRes_Import - N_NRenRes_Usage) * dt

INIT N_NRenRes_Stock = 1.1*N_EngDmd_Total

N_NRenRes_Import = R_NRenRes_SuppliedTo_N

N_NRenRes_Usage = N_EngUsage_NRen/NRen_EngToRes_ConvFactor

N_NRen_Scar_Perc(t) = N_NRen_Scar_Perc(t - dt) + (N_NRen_Scar_Perc_Chg) * dt

INIT N_NRen_Scar_Perc = R_NRenRes_ResvToDmd

N_NRen_Scar_Perc_Chg = (R_NRenRes_ResvToDmd-N_NRen_Scar_Perc)/N_NRen_Scar_Perc_Delay

N_RenEngPerCap(t) = N_RenEngPerCap(t - dt) + (N_REPC_Impr) * dt

INIT N_RenEngPerCap = N_RenEngPerCap_Ini

N_REPC_Impr = N_RenEngPerCap*N_REPC_Impr_Frac

N_RenEngPerCap_Eff(t) = N_RenEngPerCap_Eff(t - dt) + (N_REPC_Diff) * dt

INIT N_RenEngPerCap_Eff = N_RenEngPerCap_Ini*1.05

N_REPC_Diff = (N_RenEngPerCap-N_RenEngPerCap_Eff)/N_REPC_Diff_Delay

Eng_Common_Frac = 0.15

G_REPC_L = R_NRenEngPerCap_Norm*1.2

N_EnergySafetyFactor = 1

N_EngCapa_NRen = N_NRenRes_Stock*NRen_EngToRes_ConvFactor/N_NRenRes_Usage_Delay

N_EngCapa_Ren_Adj = (N_EngCapa_Ren_Des-N_EngCapa_Ren)/N_EngCapa_Ren_AdjDelay+N_EngCapa_Ren_Dep_Exp

N_EngCapa_Ren_AdjDelay = 5

N_EngCapa_Ren_Dep_Exp = N_EngCapa_Ren_Des/Cap_Lifetime

N_EngCapa_Ren_Des = N_EngDmd_Ren_Exp*1.05

N_EngCapa_Ren_InstDelay = 20

N_EngCapa_Ren_Inv_Max = N_Inv*N_RenEngInv_Frac_Max*N_RenEngPerCap_Eff

N_EngCapa_Ren_Ordered_Des = N_EngCapa_Ren_Adj*N_EngCapa_Ren_InstDelay

N_EngCapa_Total = N_EngCapa_Ren+N_EngCapa_NRen

N_EngCap_Ren_Ordered_Adj = (N_EngCapa_Ren_Ordered_Des-N_EngCapa_Ren_Ordered)/N_EngCapa_Ren_AdjDelay

N_EngDemand_NRen_%Chg = TREND(N_EngDmd_NRen,3,0.05)

N_EngDmd_%Chg_PercDelay = 5

N_EngDmd_NRen = N_EngDmd_NRen_Pr+N_EngDmd_NRen_Ren

N_EngDmd_NRen_Pr = (1-N_EngDmd_RenFrac)*N_EngDmd_Total

N_EngDmd_NRen_Ren = MIN(N_EngShortage_Ren,N_EngSurplus_NRen)

N_EngDmd_Ren = N_EngDmd_Ren_Pr+N_EngDmd_Ren_NRen

N_EngDmd_RenFrac_Goal = MAX(N_EngDmd_RenFrac_GoalScar,N_EngDmd_RenFrac_GoalCo2)

N_EngDmd_RenFrac_Ini = 0.02

N_EngDmd_Ren_%Chg = TREND(N_EngDmd_Ren,dt,0.04)

N_EngDmd_Ren_Exp = N_EngDmd_Ren*(1+N_EngDmd_Ren_%Chg_Perc)^N_EngCapa_Ren_AdjDelay

N_EngDmd_Ren_NRen = MIN(N_EngSurplus_Ren,N_EngShortage_NRen)

N_EngDmd_Ren_Pr = N_EngDmd_RenFrac*N_EngDmd_Total

N_EngDmd_Total = (N_OutputCapa_Cap)*(N_EngPerOutput)

N_EngShortage_NRen = MAX(0,N_EngDmd_NRen_Pr-N_EngCapa_NRen)*Eng_Common_Frac

N_EngShortage_Ren = MAX(0,N_EngDmd_Ren_Pr-N_EngCapa_Ren)*Eng_Common_Frac

N_EngSurplus_NRen = MAX(0,N_EngCapa_NRen-N_EngDmd_NRen_Pr)*Eng_Common_Frac

N_EngSurplus_Ren = MAX(0, N_EngCapa_Ren-N_EngDmd_Ren_Pr)*Eng_Common_Frac

N_EngUsage_Frac_Ren = N_EngUsage_Ren/N_EngUsage_Total

N_EngUsage_NRen = MIN(N_EngDmd_NRen,N_EngCapa_NRen)

N_EngUsage_Ren = MIN(N_EngDmd_Ren,N_EngCapa_Ren)

N_EngUsage_Total = N_NRenRes_Usage+N_EngUsage_Ren

N_Eng_PolImp_Delay = 20

N_NRenRes_Imp_Dmd = N_NRenRes_Stock_Des-N_NRenRes_Remain

N_NRenRes_Remain = MAX(N_EngCapa_NRen-N_NRenRes_Usage,0)

N_NRenRes_Stock_Des = N_EngDmd_NRen*(1+N_EngDemand_NRen_%Chg)*N_EnergySafetyFactor

N_NRenRes_Usage_Delay = 1

N_NRen_Scar_Perc_Delay = 10

N_RenEngInv_Des = N_EngCapa_Ren_Adj+N_EngCap_Ren_Ordered_Adj

N_RenEngInv_Frac_Max = 0.3

N_RenEngPerCap_Ini = R_NRenEngPerCap_Norm/N_REPC_Ini_Fact

N_RenEng_Inv = N_EngCapa_Ren_Inv/N_RenEngPerCap_Eff

N_RenEng_P_Index = 1/N_RenEngPerCap_Eff

N_REPC_Diff_Delay = 30

N_REPC_Impr_Frac =

N_REPC_Impr_Mult_RD*N_REPC_Impr_Mult_MC*N_REPC_Impr_Frac_Norm

N_REPC_Impr_Frac_Norm = 0.01

N_REPC_Impr_Mult_RD = N_RenEng_RD_Mult_Inc*N_RenEng_RD_Mult_Scar

N_REPC_Ini_Fact = 3

N_EngDmd_RenFrac_GoalScar = GRAPH(N_NRen_Scar_Perc)

(5.00, 1.00), (9.50, 0.765), (14.0, 0.57), (18.5, 0.41), (23.0, 0.285), (27.5, 0.19), (32.0, 0.12), (36.5, 0.065), (41.0, 0.035), (45.5, 0.025), (50.0, 0.015)

N_EngDmd_RenFrac_Mult_Tech = GRAPH(N_RenEngPerCap_Eff/R_NRenEngPerCap)

(0.00, 0.00), (0.2, 0.31), (0.4, 0.61), (0.6, 0.83), (0.8, 0.95), (1.00, 1.00), (1.20, 1.03), (1.40, 1.17), (1.60, 1.39), (1.80, 1.67), (2.00, 2.00)

N_EngPerOutput = GRAPH(time)

(1975, 0.609), (1980, 0.441), (1985, 0.339), (1990, 0.269), (1995, 0.23), (2000, 0.206)

N_NRenRes_Usage_Real = GRAPH(time)

(1975, 3e+006), (1980, 3.2e+006), (1985, 3e+006), (1990, 3.2e+006), (1995, 3.4e+006), (2000, 3.6e+006)

N_RenEng_RD_Mult_Inc = GRAPH(N_OPC_Index)

(0.00, 1.00), (5.00, 1.95), (10.0, 3.90), (15.0, 6.75), (20.0, 9.00), (25.0, 10.8), (30.0, 12.6), (35.0, 13.5), (40.0, 14.3), (45.0, 14.5), (50.0, 15.0)

N_RenEng_RD_Mult_Scar = GRAPH(N_NRen_Scar_Perc)

(0.00, 4.93), (10.0, 4.17), (20.0, 3.43), (30.0, 2.83), (40.0, 2.35), (50.0, 1.93), (60.0, 1.58), (70.0, 1.30), (80.0, 1.10), (90.0, 1.03), (100, 1.00)

N_REPC_Impr_Mult_MC = GRAPH(N_RenEngPerCap/G_REPC_L)

(0.00, 1.00), (0.1, 0.67), (0.2, 0.43), (0.3, 0.285), (0.4, 0.205), (0.5, 0.135), (0.6, 0.085), (0.7, 0.05), (0.8, 0.025), (0.9, 0.005), (1, 0.0001)

N_ChildMortFrac_Perc(t) = N_ChildMortFrac_Perc(t - dt) + (N_CMF_Perc_Chg) * dt

INIT N_ChildMortFrac_Perc = N_DeathFrac_PreRepro

N_CMF_Perc_Chg = (N_DeathFrac_PreRepro-N_ChildMortFrac_Perc)/G_LifeExpPerc_Delay

N_OPC_Perc(t) = N_OPC_Perc(t - dt) + (N_OPC_Perc_Chg) * dt

INIT N_OPC_Perc = N_OutputPerCapita

N_OPC_Perc_Chg = (N_OutputPerCapita-N_OPC_Perc)/G_OPC_Perc_Delay

N_Pop_PostRepro(t) = N_Pop_PostRepro(t - dt) + (N_ReproToPostRepro - N_Deaths_PostRepro) * dt

INIT N_Pop_PostRepro = 170

N_ReproToPostRepro = N_Pop_Repro*G_MatFromRepro_Frac*(1-N_DeathFrac_Repro)

```
N_Deaths_PostRepro = N_Pop_PostRepro*N_DeathFrac_PostRepro
N_Pop_PreRepro(t) = N_Pop_PreRepro(t - dt) + (N_Births - N_PreReproToRepro -
N_Deaths_PreRepro) * dt
INIT N_Pop_PreRepro = 215
N_Births = 0.5*N_Pop_Repro*N_Fertility/G_Repro_LTime
N_PreReproToRepro = N_Pop_PreRepro*G_MatToRepro_Frac*(1-N_DeathFrac_PreRepro)
N_Deaths_PreRepro = N_Pop_PreRepro*N_DeathFrac_PreRepro
N_Pop_Repro(t) = N_Pop_Repro(t - dt) + (N_PreReproToRepro - N_ReproToPostRepro -
N_Deaths_Repro) * dt
INIT N_Pop_Repro = 280
N_PreReproToRepro = N_Pop_PreRepro*G_MatToRepro_Frac*(1-N_DeathFrac_PreRepro)
N_ReproToPostRepro = N_Pop_Repro*G_MatFromRepro_Frac*(1-N_DeathFrac_Repro)
N_Deaths_Repro = N_Pop_Repro*N_DeathFrac_Repro
N_UrbPop_Frac(t) = N_UrbPop_Frac(t - dt) + (N_UrbPop_Chg) * dt
INIT N_UrbPop_Frac = 0.733
N_UrbPop_Chg = N_RuralPopFrac*N_UrbtionFrac
G_Co2_Conc = 1.5194*(time-1975)+331
G_Fert_Nrm = 12
G_LabForce_PartFrac = 0.45
G_MatFromRepro_Frac = 1/30
G_MatToRepro_Frac = 1/15
G_Repro_LTime = 30
N_Co2_Ems_Index = N_Co2_Ems/INIT(N_Co2_Ems)
N_Fertility = MIN(N_Fert_Exp, (N_Fert_Exp*(1-
N_FertControlEffnesss)+N_Fertility_Des*N_FertControlEffnesss))
N_Fertility_Des = N_NoOfChild_Des*N_Fert_Mult_ChildMort
N_Fert_Exp = G_Fert_Nrm*N_Fert_Mult_LifeExp
N_HServPerCapita_Index = N_OPC_Index*N_IncToHealth_Frac_Index
N_LabForce = G_LabForce_PartFrac*N_Population
N_LandArea = 31533596
N_LifeExp =
N_LifeExp_Ini*N_LifeExp_Mult_HServ*N_LifeExp_Mult_UrbPol*N_LifeExp_Mult_GlbPol
N_LifeExp_Ini = 68
N_LifeExp_Mult_UrbPol = 1-(N_UrbPop_Frac*N_LifeExp_Decr_UrbPol)
N_NoOfChild_Des = N_NoOfChild_Ini*N_NoOfChild_Mult_OPC
```

N_NoOfChild_Ini = 2.5

N_PopDensity = N_Population/N_LandArea

N_Population = N_Pop_PostRepro+N_Pop_PreRepro+N_Pop_Repro

N_RuralPopFrac = 1-N_UrbPop_Frac

N_UrbtionFrac =

N_UrbtionFrac_Ini*N_UrbtionFrac_Mult_UrbEcon*N_UrbtionFrac_Mult_PopDens*N_UrbtionFrac_Mult_CL

N_UrbtionFrac_Ini = 0.02

N_DeathFrac_PostRepro = GRAPH(N_LifeExp)

(20.0, 0.056), (30.0, 0.0438), (40.0, 0.0366), (50.0, 0.0318), (60.0, 0.0279), (70.0, 0.0258), (80.0, 0.0246)

N_DeathFrac_PreRepro = GRAPH(N_LifeExp)

(20.0, 0.065), (30.0, 0.043), (40.0, 0.03), (50.0, 0.022), (60.0, 0.0165), (70.0, 0.0135), (80.0, 0.012)

N_DeathFrac_Repro = GRAPH(N_LifeExp)

(20.0, 0.027), (30.0, 0.0204), (40.0, 0.0147), (50.0, 0.0107), (60.0, 0.00825), (70.0, 0.00675), (80.0, 0.00555)

N_FertControlEffnesss = GRAPH(time)

(1975, 0.85), (1983, 0.876), (1990, 0.899), (1998, 0.915), (2005, 0.931), (2013, 0.946), (2020, 0.958), (2028, 0.969), (2035, 0.979), (2043, 0.986), (2050, 0.99)

N_Fert_Mult_ChildMort = GRAPH(N_ChildMortFrac_Perc/INIT(N_ChildMortFrac_Perc))

(0.00, 0.48), (0.2, 0.525), (0.4, 0.63), (0.6, 0.75), (0.8, 0.885), (1.00, 1.03), (1.20, 1.23), (1.40, 1.45), (1.60, 1.70), (1.80, 1.99), (2.00, 2.34)

N_Fert_Mult_LifeExp = GRAPH(N_LifeExp)

(0.00, 0.00), (10.0, 0.195), (20.0, 0.385), (30.0, 0.565), (40.0, 0.715), (50.0, 0.83), (60.0, 0.91), (70.0, 0.96), (80.0, 1.00)

N_IncToHealth_Frac_Index = GRAPH(N_OPC_Index)

(0.00, 0.67), (1.00, 0.999), (2.00, 1.22), (3.00, 1.42), (4.00, 1.55), (5.00, 1.65), (6.00, 1.72), (7.00, 1.77), (8.00, 1.81), (9.00, 1.84), (10.0, 1.86)

N_LifeExp_Decr_UrbPol = GRAPH(N_Co2_Ems_Index)

(0.00, -0.026), (0.5, -0.014), (1.00, 0.00), (1.50, 0.017), (2.00, 0.035), (2.50, 0.053), (3.00, 0.077), (3.50, 0.098), (4.00, 0.128), (4.50, 0.155), (5.00, 0.185)

N_LifeExp_Mult_GlbPol = GRAPH(G_Co2_Atm/INIT(G_Co2_Atm))

(0.5, 1.01), (0.75, 1.01), (1.00, 1.00), (1.25, 0.992), (1.50, 0.982), (1.75, 0.97), (2.00, 0.956), (2.25, 0.941), (2.50, 0.922), (2.75, 0.904), (3.00, 0.886)

N_LifeExp_Mult_HServ = GRAPH(N_HServPerCapita_Index)

(0.00, 1.00), (1.00, 1.05), (2.00, 1.09), (3.00, 1.13), (4.00, 1.15), (5.00, 1.18), (6.00, 1.20), (7.00, 1.22), (8.00, 1.24), (9.00, 1.24), (10.0, 1.25)

N_LifeExp_Real = GRAPH(time)

(1975, 72.5), (1980, 73.8), (1985, 75.0), (1990, 76.0), (1995, 76.8), (2000, 78.0)

N_NoOfChild_Mult_OPC = GRAPH(N_OPC_Perc/INIT(N_OPC_Perc))

(0.00, 1.14), (1.00, 1.01), (2.00, 0.924), (3.00, 0.84), (4.00, 0.763), (5.00, 0.714), (6.00, 0.672), (7.00, 0.651), (8.00, 0.63), (9.00, 0.616), (10.0, 0.616)

N_Population_Real = GRAPH(time)

(1975, 671), (1976, 675), (1977, 680), (1978, 685), (1979, 690), (1980, 694), (1981, 699), (1982, 704), (1983, 708), (1984, 711), (1985, 715), (1986, 719), (1987, 723), (1988, 728), (1989, 733), (1990, 738), (1991, 743), (1992, 748), (1993, 754), (1994, 759), (1995, 764), (1996, 769), (1997, 774), (1998, 779), (1999, 784), (2000, 789), (2001, 795)

N_UrbPop_Frac_Real = GRAPH(time)

(1975, 0.737), (1976, 0.738), (1977, 0.74), (1978, 0.742), (1979, 0.744), (1980, 0.746), (1981, 0.748), (1982, 0.749), (1983, 0.752), (1984, 0.754), (1985, 0.756), (1986, 0.758), (1987, 0.76), (1988, 0.763), (1989, 0.765), (1990, 0.768), (1991, 0.77), (1992, 0.772), (1993, 0.774), (1994, 0.777), (1995, 0.779), (1996, 0.781), (1997, 0.783), (1998, 0.785), (1999, 0.787), (2000, 0.789), (2001, 0.791)

N_UrbtionFrac_Mult_CL = GRAPH(N_UrbPop_Frac)

(0.6, 1.00), (0.64, 0.98), (0.68, 0.945), (0.72, 0.875), (0.76, 0.75), (0.8, 0.58), (0.84, 0.375), (0.88, 0.22), (0.92, 0.115), (0.96, 0.045), (1.00, 0.02)

N_UrbtionFrac_Mult_PopDens = GRAPH(N_PopDensity/INIT(N_PopDensity))

(0.00, 0.7), (0.2, 0.705), (0.4, 0.725), (0.6, 0.775), (0.8, 0.875), (1.00, 1.00), (1.20, 1.10), (1.40, 1.16), (1.60, 1.19), (1.80, 1.20), (2.00, 1.20)

N_UrbtionFrac_Mult_UrbEcon = GRAPH(N_OPC_Index)

(0.00, 0.87), (1.00, 1.00), (2.00, 1.07), (3.00, 1.11), (4.00, 1.13), (5.00, 1.14), (6.00, 1.15), (7.00, 1.15), (8.00, 1.15), (9.00, 1.16), (10.0, 1.16)

R_NRenRes_Resv(t) = R_NRenRes_Resv(t - dt) + (R_NRenRes_Discv - R_NRenRes_Prod) * dt

INIT R_NRenRes_Resv = R_NRenRes_Resv_Ini

R_NRenRes_Discv = R_NRenRes_UDResv*R_NRenRes_DiscvFrac

R_NRenRes_Prod = R_NRenRes_ProdCapa*R_NRenRes_Prod_Mult_Dmd

R_NRenRes_UDResv(t) = R_NRenRes_UDResv(t - dt) + (- R_NRenRes_Discv) * dt

INIT R_NRenRes_UDResv = R_NRenRes_UDResv_Ini

R_NRenRes_Discv = R_NRenRes_UDResv*R_NRenRes_DiscvFrac

G_OutputToNRen_VIndex = G_OutputToNRen_VIndex_Ini/R_NRenEng_VIndex

G_OutputToNRen_VIndex_Ini = 4

R_NRenEngPerCap = R_NRenEngPerCap_Mult_FracRem*R_NRenEngPerCap_Norm

R_NRenEngPerCap_Norm = 0.9

R_NRenRes_BaseToProd = R_NRenRes_TotalBase/R_NRenRes_Prod

R_NRenRes_DiscvFrac =

R_NRenRes_DiscvFrac_Norm*R_NRenRes_DiscvFrac_Mult_FracRem*R_NRenRes_DiscvFrac_Mult_Resv

R_NRenRes_DiscvFrac_Norm = 0.02

R_NRenRes_DmdProd = R_NRenRes_Dmd_Total/R_NRenRes_Prod

R_NRenRes_Dmd_Nfrac = N_NRenRes_Imp_Dmd/R_NRenRes_Dmd_Total

R_NRenRes_Dmd_Sfrac = S_NRenRes_Imp_Dmd/R_NRenRes_Dmd_Total

R_NRenRes_Dmd_Total =

N_NRenRes_Imp_Dmd+R_NRenRes_Imp_Dmd+S_NRenRes_Imp_Dmd

R_NRenRes_FracRem = (R_NRenRes_TotalBase/INIT(R_NRenRes_TotalBase))

R_NRenRes_Imp_Dmd = 0.28*(N_NRenRes_Imp_Dmd+S_NRenRes_Imp_Dmd)

R_NRenRes_ProdCapa = R_NRenRes_Resv*R_NRenRes_Prod_Frac

R_NRenRes_Prod_Frac = 0.1

R_NRenRes_ResvToDmd = R_NRenRes_Resv/R_NRenRes_Dmd_Total

R_NRenRes_ResvToProd = R_NRenRes_Resv/R_NRenRes_Prod

R_NRenRes_Resv_Ini = 170000000

R_NRenRes_SuppliedTo_N = R_NRenRes_Prod*R_NRenRes_Dmd_Nfrac

R_NRenRes_SuppliedTo_RoW = (1-R_NRenRes_Dmd_Nfrac-R_NRenRes_Dmd_Sfrac)*R_NRenRes_Prod

R_NRenRes_SuppliedTo_S = R_NRenRes_Prod*R_NRenRes_Dmd_Sfrac

R_NRenRes_TotalBase = R_NRenRes_Resv+R_NRenRes_UDResv

R_NRenRes_UDResv_Ini = 600000000

R_NRenRes_Usage = DELAY(R_NRenRes_SuppliedTo_RoW,dt)

R_NRenEngPerCap_Mult_FracRem = GRAPH(R_NRenRes_FracRem)

(0.00, 0.00), (0.1, 0.185), (0.2, 0.35), (0.3, 0.505), (0.4, 0.64), (0.5, 0.74), (0.6, 0.81), (0.7, 0.875), (0.8, 0.935), (0.9, 0.98), (1, 1.00)

R_NRenEng_VIndex = GRAPH(INIT(R_NRenEngPerCap)/R_NRenEngPerCap)

(1.00, 1.00), (1.90, 1.31), (2.80, 1.63), (3.70, 2.04), (4.60, 2.67), (5.50, 3.70), (6.40, 5.25), (7.30, 7.15), (8.20, 8.35), (9.10, 9.20), (10.0, 9.75)

R_NRenRes_DiscvFrac_Mult_FracRem =

GRAPH(R_NRenRes_UDResv/INIT(R_NRenRes_UDResv))

(0.00, 0.00), (0.1, 0.48), (0.2, 0.74), (0.3, 0.845), (0.4, 0.9), (0.5, 0.94), (0.6, 0.965), (0.7, 0.98), (0.8, 0.985), (0.9, 0.995), (1, 1.00)

R_NRenRes_DiscvFrac_Mult_Resv = GRAPH(R_NRenRes_ResvToDmd)

(0.00, 1.71), (20.0, 1.56), (40.0, 1.29), (60.0, 0.89), (80.0, 0.58), (100, 0.3), (120, 0.15), (140, 0.06), (160, 0.02), (180, 0.01), (200, 0.01)

R_NRenRes_Prod_Mult_Dmd = GRAPH(R_NRenRes_Dmd_Total/R_NRenRes_ProdCapa)

(0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.485), (0.6, 0.57), (0.7, 0.655), (0.8, 0.725), (0.9, 0.785), (1, 0.84), (1.10, 0.885), (1.20, 0.915)

S_CapForHTech_Frac(t) = S_CapForHTech_Frac(t - dt) + (S_CapShift_LtoH - S_CapShift_HtoL) * dt

INIT S_CapForHTech_Frac = 1-S_CapForLTech_Frac

S_CapShift_LtoH =

S_CapShift_Nrm*S_CapShift_LtoH_Mult_Short*S_CapShft_LtoH_Mult_Limit*S_CapShift_LtoH_Mult_MR

S_CapShift_HtoL =

S_CapShift_Nrm*S_CapShift_HtoL_Mult_Short*S_CapShift_HtoL_Mult_Limit*S_CapShift_HtoL_Mult_MR

S_CapForLTech_Frac(t) = S_CapForLTech_Frac(t - dt) + (S_CapShift_HtoL - S_CapShift_LtoH) * dt

INIT S_CapForLTech_Frac = S_CapForLTech_Frac_Ini

S_CapShift_HtoL =

S_CapShift_Nrm*S_CapShift_HtoL_Mult_Short*S_CapShift_HtoL_Mult_Limit*S_CapShift_HtoL_Mult_MR

S_CapShift_LtoH =

S_CapShift_Nrm*S_CapShift_LtoH_Mult_Short*S_CapShft_LtoH_Mult_Limit*S_CapShift_LtoH_Mult_MR

S_Capital(t) = S_Capital(t - dt) + (S_CapInv - S_CapDepr) * dt

INIT S_Capital = S_Capital_Ini

S_CapInv = S_Inv-S_RenEngInv

S_CapDepr = S_Capital/Cap_LifeTime

S_CapTech(t) = S_CapTech(t - dt) + (S_CapTechDiff) * dt

INIT S_CapTech = S_CapTech_Ini

S_CapTechDiff = (S_CapTech_New-S_CapTech)/S_TechDiff_Delay

S_CapTech_New(t) = S_CapTech_New(t - dt) + (S_CapTech_Assim) * dt

INIT S_CapTech_New = S_CapTech_New_Ini

```
S_CapTech_Assim = (N_CapTech*N_TechTrans_Coef-S_CapTech_New)/S_TechTrans_Delay
S_Debt(t) = S_Debt(t - dt) + (S_Debt_Interest + S_New_Debt - S_Debt_Payment - S_DebtRelief)
* dt
INIT S_Debt = S_Debt_Ini
S_Debt_Interest = S_Debt*S_Debt_IR
S_New_Debt = S_FCU_Crd
S_Debt_Payment = S_DebtPayment_Des
S_DebtRelief = S_Debt*S_DebtRelief_Frac
S_DebtServ_Ratio_Perc(t) = S_DebtServ_Ratio_Perc(t - dt) + (S_DSI_Perc_Chg) * dt
INIT S_DebtServ_Ratio_Perc = 0.05
S_DSI_Perc_Chg = (S_FCU_ActToDes-S_DebtServ_Ratio_Perc)/S_DSI_Perc_Delay
S_FCU_Stock(t) = S_FCU_Stock(t - dt) + (S_Exp_Inc + S_FCU_Crd + S_IntAid - S_Imp_Paym -
S_Debt_Paym) * dt
INIT S_FCU_Stock = S_FCU_Stock_Ini
S_Exp_Inc = S_ExpTo_N*S_FCU_Factor
S_FCU_Crd = S_FCU_Stock_Des-(S_FCU_Stock+S_FCU_Inflow-S_FCU_Outflow)
S_IntAid = GRAPH(time)
(1975, 6000), (1983, 6000), (1990, 8000), (1998, 13000), (2005, 22000), (2013, 34500), (2020,
54000), (2028, 72000), (2035, 81000), (2043, 86000), (2050, 89000)
S_Imp_Paym = S_ImpFr_N*S_FCU_Factor
S_Debt_Paym = S_Debt_Payment
S_LabSkill_HTech(t) = S_LabSkill_HTech(t - dt) + (S_LSHT_Chg) * dt
INIT S_LabSkill_HTech = S_LabSkill_HTech_Ini
S_LSHT_Chg = S_LSHT_Chg_Norm*S_LSHT_Chg_Mult_Prod*S_LSHT_Chg_Mult_CurLS
S_LabSkill_LTech(t) = S_LabSkill_LTech(t - dt) + (S_LSLT_Chg) * dt
INIT S_LabSkill_LTech = S_LabSkill_LTech_Ini
S_LSLT_Chg = S_LSLT_Chg_Norm*S_LSLT_Chg_Mult_Prod*S_LSLT_Chg_Mult_CurLS
Key_Debt = 0
Key_TechTrans_Trade = 0
S_CapForHTech = S_Capital*(1-S_CapForLTech_Frac)
S_CapForLTech = S_Capital*S_CapForLTech_Frac
S_CapForLTech_Frac_Ini = 0.4
S_Capital_Ini = 4000000
S_CapShift_HtoL_Mult_Short = MAX(0,S_LTech_DmdToOutput-1)
S_CapShift_LtoH_Mult_Short = MAX(0,S_HTech_DmdToOutput-1)
```

S_CapShift_Nrm = 0.5

S_CapTech_Avg = S_CapTech

S_CapTech_Ini = 1

S_CapTech_New_Ini = 1

S_CapUtil_Eng = MIN(1,S_OutputCapa_Eng/S_OutputCapa_Cap)

S_Cons_Des = (1-S_Inv_Frac)*S_Output_Net

S_DebtPayment_Des = S_Debt/S_Debt_AvgTerm

S_DebtToExp = S_Debt/S_Exp_Inc

S_Debt_AvgTerm = 10

S_Debt_Ini = 65000

S_Debt_IR = 0.05

S_DSI_Perc_Delay = 5

S_FCU_ActToDes = S_FCU_Stock/S_FCU_Stock_Des

S_FCU_Factor = 1

S_FCU_Inflow = S_Exp_Inc+S_IntAid

S_FCU_Outflow = S_Debt_Paym+S_Imp_Paym

S_FCU_Stock_Des = S_Imp_Paym*0.2

S_FCU_Stock_Ini = 30000

S_HTech_Avail = N_HTech_STo_S+S_HTech_STo_S

S_HTech_Avail_ForInv = S_HTech_Avail*S_HTech_InvFracInDmd

S_HTech_Des = S_HTech_Des_ForCons+S_HTech_Des_ForInv

S_HTech_DesToAvail = S_HTech_Des/S_HTech_Avail

S_HTech_Des_ForCons = S_Cons_Des*(1-S_LTechFrac_ForCons)

S_HTech_Des_ForInv = S_Inv_Des*(1-S_LTechFrac_ForInv)

S_HTech_EffLab_Mult_Skill = S_LabSkill_HTech/INIT(S_LabSkill_HTech)

S_HTech_InvFracInDmd = S_HTech_Des_ForInv/S_HTech_Des

S_HTech_LabPerCap = S_LabForHTech_Eff/S_CapForHTech

S_HTech_LPC_Index = S_HTech_LabPerCap/INIT(S_HTech_LabPerCap)

S_HTech_Output = S_CapUtil_Eng*S_HTech_Output_Capa

S_HTech_Output_Capa = S_CapForHTech*S_Pvity_HTech

S_Inv = MIN(S_Inv_Max_HTech,S_Inv_Max_LTech)

S_Inv_Des = S_Output_Net*S_Inv_Frac

S_Inv_Frac = 0.25

S_Inv_Max_HTech = S_HTech_Avail_ForInv/(1-S_LTechFrac_ForInv)

S_Inv_Max_LTech = S_LTech_Avail_ForInv/S_LTechFrac_ForInv

S_LabForHTech = (1-S_LabForLTech_Frac)*S_LabForce

S_LabForHTech_Eff = S_LabForHTech*S_HTech_EffLab_Mult_Skill

S_LabForLTech = S_LabForLTech_Frac*S_LabForce

S_LabForLTech_Eff = S_LabForLTech*S_LTech_EffLab_Mult_Skill

S_LabForLTech_Frac = S_CapForLTech_Frac

S_LabSkill_HTech_Ini = 0.6

S_LabSkill_LTech_Ini = 1

S_LSHT_Chg_Mult_Prod = S_OutputPerLab_HTech/INIT(S_OutputPerLab_HTech)

S_LSHT_Chg_Norm = 0.005

S_LSLT_Chg_Mult_Prod = S_OutputPerLab_LTech/INIT(S_OutputPerLab_LTech)

S_LSLT_Chg_Norm = 0.01

S_LTechFrac_ForCons = S_LTechFrac_ForCons_Ini*S_LTForCons_Mult_OPC

S_LTechFrac_ForCons_Ini = 0.9

S_LTechFrac_ForInv = S_LTechFrac_ForInv_Ini*S_LTForInv_Mult_OPC

S_LTechFrac_ForInv_Ini = 0.8

S_LTech_Avail = N_LTech_STo_S+S_LTech_STo_S

S_LTech_Avail_ForInv = S_LTech_Avail*S_LTech_InvFracInDmd

S_LTech_Des = S_LTech_Des_ForCons+S_LTech_Des_ForInv

S_LTech_DesToAvail = S_LTech_Des/S_LTech_Avail

S_LTech_Des_ForCons = S_Cons_Des*S_LTechFrac_ForCons

S_LTech_Des_ForInv = S_Inv_Des*S_LTechFrac_ForInv

S_LTech_EffLab_Mult_Skill = S_LabSkill_LTech/INIT(S_LabSkill_LTech)

S_LTech_InvFracInDmd = S_LTech_Des_ForInv/S_LTech_Des

S_LTech_LabPerCap = S_LabForLTech_Eff/S_CapForLTech

S_LTech_LPC_Index = S_LTech_LabPerCap/INIT(S_LTech_LabPerCap)

S_LTech_Output = S_CapUtil_Eng*S_LTech_Output_Capa

S_LTech_Output_Capa = S_CapForLTech*S_Pvity_LTech

S_MargRet_HtoL = S_Pvity_LTech-S_Pvity_HTech

S_MargRet_LtoH = S_Pvity_HTech-S_Pvity_LTech

S_OPC_Index = S_OutputPerCapita/INIT(S_OutputPerCapita)

S_Output = S_HTech_Output+S_LTech_Output

S_OutputCapa_Cap = S_HTech_Output_Capa+S_LTech_Output_Capa

S_OutputCapa_Eng = S_EngCapa_Total/S_EngPerOutput

S_OutputFrN_Frac = S_ImpFr_N/S_Output_Avail

S_OutputPerCapita = S_Output_Net/S_Population

S_OutputPerLab_HTech = S_HTech_Output/S_LabForHTech

S_OutputPerLab_LTech = S_LTech_Output/S_LabForLTech

S_Output_Avail = S_HTech_Avail+S_LTech_Avail

S_Output_Net = S_Output*(1-S_Output_Frac_ForEng)

S_PvityHTech_Norm = 0.3

S_PvityLTech_Norm = 0.5

S_Pvity_HTech = if Key=1 then

S_PvityHTech_Norm*S_PvityHTech_Mult_LPC*S_PvityHTech_Mult_CT else

S_Pvity_HTech_Test

S_Pvity_HTech_Test = 0.4

S_Pvity_LTech = if Key=1 then

S_PvityLTech_Norm*S_PvityLTech_Mult_CT*S_PvityLTech_Mult_LPC else

S_Pvity_LTech_Test

S_Pvity_LTech_Test = 0.4

S_TechDiff_Delay = 15

S_TechTrans_Delay = S_TechTrans_Delay_Ini*S_TechTrans_Mult_Trade

S_TechTrans_Delay_Ini = 30

S_TechTrans_Mult_Trade = if Key_TechTrans_Trade=0 then 1 else S_TechTrans_Mult_Trade1

N_TechTrans_Coef = GRAPH(time)

(1995, 0.505), (2000, 0.505), (2005, 0.5), (2010, 0.5), (2015, 0.5), (2020, 0.5), (2025, 0.505), (2030, 0.505), (2035, 0.505), (2040, 0.505), (2045, 0.505), (2050, 0.505)

S_CapShft_LtoH_Mult_Limit = GRAPH(S_CapForLTech_Frac)

(0.00, 0.00), (0.01, 0.45), (0.02, 0.7), (0.03, 0.84), (0.04, 0.905), (0.05, 0.94), (0.06, 0.96), (0.07, 0.985), (0.08, 1.00), (0.09, 1.00), (0.1, 1.00)

S_CapShift_HtoL_Mult_Limit = GRAPH(S_CapForHTech_Frac)

(0.00, 0.00), (0.01, 0.45), (0.02, 0.7), (0.03, 0.84), (0.04, 0.905), (0.05, 0.94), (0.06, 0.96), (0.07, 0.985), (0.08, 1.00), (0.09, 1.00), (0.1, 1.00)

S_CapShift_HtoL_Mult_MR = GRAPH(S_MargRet_HtoL)

(-1.00, 0.00), (-0.8, 0.04), (-0.6, 0.13), (-0.4, 0.3), (-0.2, 0.6), (-5.55e-017, 1.00), (0.2, 1.29), (0.4, 1.51), (0.6, 1.68), (0.8, 1.80), (1.00, 1.86)

S_CapShift_LtoH_Mult_MR = GRAPH(S_MargRet_LtoH)

(-1.00, 0.00), (-0.8, 0.04), (-0.6, 0.13), (-0.4, 0.3), (-0.2, 0.6), (-5.55e-017, 1.00), (0.2, 1.29), (0.4, 1.51), (0.6, 1.68), (0.8, 1.80), (1.00, 1.86)

S_DebtRelief_Frac = GRAPH(time)

(1975, 0.00), (1983, 0.00), (1990, 0.00), (1998, 0.00), (2005, 0.00), (2013, 0.00), (2020, 0.00), (2028, 0.00), (2035, 0.00), (2043, 0.00), (2050, 0.00)

S_Debt_Real = GRAPH(time)

(1975, 63780), (1980, 160073), (1985, 282032), (1990, 532201), (1995, 714775), (2000, 750713)

S_Exp_Mult_ForExcDef = GRAPH(if Key_Debt=1 then S_DebtServ_Ratio_Perc else 1)

(0.00, 1.30), (0.1, 1.29), (0.2, 1.28), (0.3, 1.24), (0.4, 1.20), (0.5, 1.13), (0.6, 1.09), (0.7, 1.06), (0.8, 1.04), (0.9, 1.02), (1, 1.00)

S_FCU_Real = GRAPH(time)

(1975, 29889), (1980, 85865), (1985, 56588), (1990, 82310), (1995, 193666), (2000, 353095)

S_Imp_Mult_ForExcDef = GRAPH(if Key_Debt=1 then S_DebtServ_Ratio_Perc else 1)

(0.00, 0.621), (0.1, 0.633), (0.2, 0.648), (0.3, 0.666), (0.4, 0.693), (0.5, 0.744), (0.6, 0.798), (0.7, 0.858), (0.8, 0.924), (0.9, 0.972), (1, 1.00)

S_LSHT_Chg_Mult_CurLS = GRAPH(S_LabSkill_HTech/INIT(S_LabSkill_HTech))

(1.00, 1.00), (1.44, 0.99), (1.89, 0.935), (2.33, 0.81), (2.78, 0.625), (3.22, 0.385), (3.67, 0.195), (4.11, 0.095), (4.56, 0.04), (5.00, 0.015)

S_LSLT_Chg_Mult_CurLS = GRAPH(S_LabSkill_LTech/INIT(S_LabSkill_LTech))

(1.00, 1.00), (2.00, 0.99), (3.00, 0.935), (4.00, 0.81), (5.00, 0.625), (6.00, 0.385), (7.00, 0.195), (8.00, 0.095), (9.00, 0.04), (10.0, 0.015)

S_LTForCons_Mult_OPC = GRAPH(S_OPC_Index)

(0.00, 1.11), (5.00, 0.888), (10.0, 0.752), (15.0, 0.664), (20.0, 0.592), (25.0, 0.536), (30.0, 0.504), (35.0, 0.472), (40.0, 0.44), (45.0, 0.416), (50.0, 0.408)

S_LTForInv_Mult_OPC = GRAPH(S_OPC_Index)

(0.00, 1.12), (5.00, 0.896), (10.0, 0.768), (15.0, 0.672), (20.0, 0.592), (25.0, 0.528), (30.0, 0.472), (35.0, 0.44), (40.0, 0.4), (45.0, 0.368), (50.0, 0.344)

S_OPC_Real = GRAPH(time)

(1975, 478), (1980, 752), (1985, 1082), (1990, 1625), (1995, 2252), (2000, 2914)

S_Output_Real = GRAPH(time)

(1975, 1.2e+006), (1980, 2e+006), (1985, 3.2e+006), (1990, 5.4e+006), (1995, 8.2e+006), (2000, 1.1e+007)

S_PvityHTech_Mult_CT = GRAPH((S_CapTech_Avg/INIT(S_CapTech_Avg)))

(0.00, 1.00), (1.00, 1.46), (2.00, 1.80), (3.00, 2.08), (4.00, 2.32), (5.00, 2.52), (6.00, 2.66), (7.00, 2.78), (8.00, 2.88), (9.00, 2.93), (10.0, 2.96)

S_PvityHTech_Mult_LPC = GRAPH(S_HTech_LPC_Index)

(0.00, 0.00), (0.2, 0.594), (0.4, 0.786), (0.6, 0.9), (0.8, 0.966), (1.00, 1.01), (1.20, 1.04), (1.40, 1.05), (1.60, 1.06), (1.80, 1.07), (2.00, 1.07)

S_PvityLTech_Mult_CT = GRAPH((S_CapTech_Avg/INIT(S_CapTech_Avg)))

(0.00, 1.00), (0.5, 1.46), (1.00, 1.80), (1.50, 2.08), (2.00, 2.32), (2.50, 2.52), (3.00, 2.66), (3.50, 2.78), (4.00, 2.88), (4.50, 2.93), (5.00, 2.96)

S_PvityLTech_Mult_LPC = GRAPH(S_LTech_LPC_Index)

(0.00, 0.00), (0.2, 0.594), (0.4, 0.786), (0.6, 0.9), (0.8, 0.966), (1.00, 1.01), (1.20, 1.04), (1.40, 1.05), (1.60, 1.06), (1.80, 1.07), (2.00, 1.07)

S_TechTrans_Mult_Trade1 = GRAPH(S_OutputFrN_Frac)

(0.00, 0.00), (10.0, 0.00), (20.0, 0.00), (30.0, 0.00), (40.0, 0.00), (50.0, 0.00), (60.0, 0.00), (70.0, 0.00), (80.0, 0.00), (90.0, 0.00), (100, 0.00)

S_EngCapa_Ren(t) = S_EngCapa_Ren(t - dt) + (S_EngCapa_Ren_Inst - S_EngCapa_Ren_Dep) * dt

INIT S_EngCapa_Ren = S_EngDmd_Total*0.02

S_EngCapa_Ren_Inst = S_EngCapa_Ren_Ordered/S_EngCapa_Ren_InstDelay

S_EngCapa_Ren_Dep = S_EngCapa_Ren/Cap_Lifetime

S_EngCapa_Ren_Ordered(t) = S_EngCapa_Ren_Ordered(t - dt) + (S_RenEngCapa_Inv - S_EngCapa_Ren_Inst) * dt

INIT S_EngCapa_Ren_Ordered = S_EngCapa_Ren_Adj*S_EngCapa_Ren_InstDelay

S_RenEngCapa_Inv = MIN(S_RenEngCapaInv_Des,S_RenEngCapaInv_Max)

S_EngCapa_Ren_Inst = S_EngCapa_Ren_Ordered/S_EngCapa_Ren_InstDelay

S_EngDmd_RenFrac(t) = S_EngDmd_RenFrac(t - dt) + (S_EngDmd_RenFrac_Chg) * dt

INIT S_EngDmd_RenFrac = S_EngDmd_RenFrac_Ini

S_EngDmd_RenFrac_Chg = (S_EngDmd_RenFrac_Goal-S_EngDmd_RenFrac)/S_Eng_PolImp_Delay*S_EngDmd_RenFrac_Mult_Tech

S_EngDmd_Ren_%Chg_Perc(t) = S_EngDmd_Ren_%Chg_Perc(t - dt) + (S_EDR_%Chg_PercChg) * dt

INIT S_EngDmd_Ren_%Chg_Perc = S_EngDmd_Ren_%Chg+0.02

S_EDR_%Chg_PercChg = (S_EngDmd_Ren_%Chg-S_EngDmd_Ren_%Chg_Perc)/S_EngDmd_%Chg_PercDelay

S_NRenRes_Stock(t) = S_NRenRes_Stock(t - dt) + (S_NRenRes_Import - S_NRenRes_Usage) * dt

INIT S_NRenRes_Stock = 1.1*S_EngDmd_Total

S_NRenRes_Import = R_NRenRes_SuppliedTo_S

S_NRenRes_Usage = S_EngUsage_NRen/NRen_EngToRes_ConvFactor

S_NRen_Scar_Perc(t) = S_NRen_Scar_Perc(t - dt) + (S_NRen_Scar_Perc_Chg) * dt

INIT S_NRen_Scar_Perc = R_NRenRes_ResvToDmd

S_NRen_Scar_Perc_Chg = (R_NRenRes_ResvToDmd-S_NRen_Scar_Perc)/S_NRen_Scar_Perc_Delay

S_RenEngPerCap(t) = S_RenEngPerCap(t - dt) + (S_REPC_Assim) * dt

INIT S_RenEngPerCap = S_RenEngPerCap_Ini

S_REPC_Assim = (N_RenEngPerCap_Eff*N_TechTrans_Coef-S_RenEngPerCap)/S_REPC_Assim_Delay

S_RenEngPerCap_Eff(t) = S_RenEngPerCap_Eff(t - dt) + (S_REPC_Diff) * dt

INIT S_RenEngPerCap_Eff = S_RenEngPerCap_Ini*1.05

S_REPC_Diff = (S_RenEngPerCap-S_RenEngPerCap_Eff)/S_REPC_DiffDelay

NRen_EngToRes_ConvFactor = 1

S_EnergySafetyFactor = 1

S_EngCapa_NRen = S_NRenRes_Stock*NRen_EngToRes_ConvFactor/S_NRenEng_Usage_Delay

S_EngCapa_Ren_Adj = (S_EngCapa_Ren_Des-S_EngCapa_Ren)/S_EngCapa_Ren_AdjDelay+S_EngCapa_Ren_Dep_Exp

S_EngCapa_Ren_AdjDelay = 5

S_EngCapa_Ren_Dep_Exp = S_EngCapa_Ren_Des/Cap_Lifetime

S_EngCapa_Ren_Des = S_EngDmd_Ren_Exp*1.05

S_EngCapa_Ren_InstDelay = 20

S_EngCapa_Ren_Ordered_Des = S_EngCapa_Ren_Adj*S_EngCapa_Ren_InstDelay

S_EngCapa_Total = S_EngCapa_Ren+S_EngCapa_NRen

S_EngCap_Ren_Ordered_Adj = (S_EngCapa_Ren_Ordered_Des-S_EngCapa_Ren_Ordered)/S_EngCapa_Ren_AdjDelay

S_EngDemand_NRen_%Chg = TREND(S_EngDmd_NRen,3,0.05)

S_EngDmd_%Chg_PercDelay = 5

S_EngDmd_NRen = S_EngDmd_NRen_Pr+S_EngDmd_NRen_Ren

S_EngDmd_NRen_Pr = (1-S_EngDmd_RenFrac)*S_EngDmd_Total

S_EngDmd_NRen_Ren = MIN(S_EngShortage_Ren,S_EngSurplus_NRen)

S_EngDmd_Ren = S_EngDmd_Ren_Pr+S_EngDmd_Ren_NRen

S_EngDmd_RenFrac_Goal = if S_GHG_Switch=1 then MAX(S_EngDmd_RenFrac_GoalCo2,S_EngDmd_RenFrac_GoalScar) else S_EngDmd_RenFrac_GoalScar

S_EngDmd_RenFrac_Ini = 0.01

S_EngDmd_Ren_%Chg = TREND(S_EngDmd_Ren,dt,0.04)

S_EngDmd_Ren_Exp = S_EngDmd_Ren*(1+S_EngDmd_Ren_%Chg_Perc)^S_EngCapa_Ren_AdjDelay

S_EngDmd_Ren_NRen = MIN(S_EngShortage_NRen,S_EngSurplus_Ren)

S_EngDmd_Ren_Pr = S_EngDmd_RenFrac*S_EngDmd_Total

S_EngDmd_Total = (S_OutputCapa_Cap)*(S_EngPerOutput)

S_EngShortage_NRen = MAX(0,S_EngDmd_NRen_Pr-S_EngCapa_NRen)*Eng_Common_Frac

S_EngShortage_Ren = MAX(0,S_EngDmd_Ren_Pr-S_EngCapa_Ren)*Eng_Common_Frac

S_EngSurplus_NRen = MAX(0,S_EngCapa_NRen-S_EngDmd_NRen_Pr)*Eng_Common_Frac

S_EngSurplus_Ren = MAX(0,S_EngCapa_Ren-S_EngDmd_Ren_Pr)*Eng_Common_Frac

S_EngUsage_Frac_Ren = S_EngUsage_Ren/S_EngUsage_Total

S_EngUsage_NRen = MIN(S_EngCapa_NRen,S_EngDmd_NRen)

S_EngUsage_Ren = MIN(S_EngDmd_Ren,S_EngCapa_Ren)

S_EngUsage_Total = S_NRenRes_Usage+S_EngUsage_Ren

S_Eng_PolImp_Delay = 20

S_GHG_Switch = 0

S_NEngRes_Remain = MAX(S_EngCapa_NRen-S_NRenRes_Usage,0)

S_NRenEng_Usage_Delay = 1

S_NRenRes_Imp_Dmd = S_NRenRes_Stock_Des-S_NEngRes_Remain

S_NRenRes_Stock_Des = S_EngDmd_NRen*(1+S_EngDemand_NRen_%Chg)*S_EnergySafetyFactor

S_NRen_Scar_Perc_Delay = 15

S_RenEngCapaInv_Des = S_EngCapa_Ren_Adj+S_EngCap_Ren_Ordered_Adj

S_RenEngCapaInv_Max = S_Inv*S_RenEngInv_Frac_Max*S_RenEngPerCap_Eff

S_RenEngInv = S_RenEngCapa_Inv/S_RenEngPerCap_Eff

S_RenEngInv_Frac_Max = 0.3

S_RenEngPerCap_Ini = R_NRenEngPerCap_Norm/S_REPC_Ini_Fact

S_RenEng_P_Index = 1/S_RenEngPerCap_Eff

S_REPC_AssimDelay_Norm = 30

S_REPC_Assim_Delay = S_REPC_AssimDelay_Norm*S_TechTrans_Mult_Trade

S_REPC_DiffDelay = 30

S_REPC_Ini_Fact = 12

S_EngDmd_RenFrac_GoalScar = GRAPH(S_NRen_Scar_Perc)

(5.00, 1.00), (9.50, 0.595), (14.0, 0.36), (18.5, 0.25), (23.0, 0.18), (27.5, 0.125), (32.0, 0.09), (36.5, 0.06), (41.0, 0.035), (45.5, 0.025), (50.0, 0.015)

S_EngDmd_RenFrac_Mult_Tech = GRAPH(S_RenEngPerCap_Eff/R_NRenEngPerCap)

```
(0.00, 0.00), (0.2, 0.31), (0.4, 0.63), (0.6, 0.85), (0.8, 0.95), (1.00, 1.00), (1.20, 1.03), (1.40, 1.15),
(1.60, 1.36), (1.80, 1.61), (2.00, 2.00)
S_EngPerOutput = GRAPH(time)
(1975, 0.5), (1980, 0.399), (1985, 0.315), (1990, 0.255), (1995, 0.224), (2000, 0.203)
S_NRenRes_Usage_Real = GRAPH(time)
(1975, 546510), (1980, 726801), (1985, 924657), (1990, 1.2e+006), (1995, 1.7e+006), (2000,
1.8e+006)
S_ChildMortFrac_Perc(t) = S_ChildMortFrac_Perc(t - dt) + (S_CMF_Perc_Chg) * dt
INIT S_ChildMortFrac_Perc = S_DeathFrac_PreRepro
S_CMF_Perc_Chg = (S_DeathFrac_PreRepro-S_ChildMortFrac_Perc)/G_LifeExpPerc_Delay
S_OPC_Perc(t) = S_OPC_Perc(t - dt) + (S_OPC_Perc_Chg) * dt
INIT S_OPC_Perc = S_OutputPerCapita
S_OPC_Perc_Chg = (S_OutputPerCapita-S_OPC_Perc)/G_OPC_Perc_Delay
S_Pop_PostRepro(t) = S_Pop_PostRepro(t - dt) + (S_ReproToPostRepro - S_Deaths_PostRepro) *
dt
INIT S_Pop_PostRepro = 500
S_ReproToPostRepro = S_Pop_Repro*G_MatFromRepro_Frac*(1-S_DeathFrac_Repro)
S_Deaths_PostRepro = S_Pop_PostRepro*S_DeathFrac_PostRepro
S_Pop_PreRepro(t) = S_Pop_PreRepro(t - dt) + (S_Births - S_PreReproToRepro -
S_Deaths_PreRepro) * dt
INIT S_Pop_PreRepro = 1000
S_Births = 0.5*S_Pop_Repro*S_Fertility/G_Repro_LTime
S_PreReproToRepro = S_Pop_PreRepro*G_MatToRepro_Frac*(1-S_DeathFrac_PreRepro)
S_Deaths_PreRepro = S_Pop_PreRepro*S_DeathFrac_PreRepro
S_Pop_Repro(t) = S_Pop_Repro(t - dt) + (S_PreReproToRepro - S_ReproToPostRepro -
S_Deaths_Repro) * dt
INIT S_Pop_Repro = 900
S_PreReproToRepro = S_Pop_PreRepro*G_MatToRepro_Frac*(1-S_DeathFrac_PreRepro)
S_ReproToPostRepro = S_Pop_Repro*G_MatFromRepro_Frac*(1-S_DeathFrac_Repro)
S_Deaths_Repro = S_Pop_Repro*S_DeathFrac_Repro
S_UrbPop_Frac(t) = S_UrbPop_Frac(t - dt) + (S_UrbPop_Chg) * dt
INIT S_UrbPop_Frac = 0.28
S_UrbPop_Chg = S_RuralPopFrac*S_UrbtionFrac
G_LifeExpPerc_Delay = 10
G_OPC_Perc_Delay = 10
```

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S_Co2_Ems_Index = S_Co2_Ems/INIT(S_Co2_Ems)
S_Fertility = MIN(S_Fert_Exp, (S_Fert_Exp*(1-S_FertControlEffness)+S_Fertility_Des*S_FertControlEffness))
S_Fertility_Des = S_NoOfChild_Des*S_Fert_Mult_ChildMort
S_Fert_Exp = G_Fert_Nrm*S_Fert_Mult_LifeExp
S_HServPerCapita_Index = S_OPC_Index*S_IncToHealth_Frac_Index
S_LabForce = G_LabForce_PartFrac*S_Population
S_LandArea = 80000000
S_LifeExp =
S_LifeExp_Ini*S_LifeExp_Mult_HServ*S_LifeExp_Mult_UrbPol*S_LifeExp_Mult_GlbPol
S_LifeExp_Ini = 40
S_LifeExp_Mult_UrbPol = 1-(S_UrbPop_Frac*S_LifeExp_Decr_UrbPol)
S_NoOfChild_Des = S_NoOfChild_Ini*S_NoOfChild_Mult_OPC
S_NoOfChild_Ini = 6
S_PopDensity = S_Population/S_LandArea
S_Population = S_Pop_PostRepro+S_Pop_PreRepro+S_Pop_Repro
S_RuralPopFrac = 1-S_UrbPop_Frac
S_UrbtionFrac =
S_UrbtionFrac_Ini*S_UrbtionFrac_Mult_UrbEcon*S_UrbtionFrac_Mult_PopDens*S_UrbtionFrac_Mult_CL
S_UrbtionFrac_Ini = 0.0075
S_DeathFrac_PostRepro = GRAPH(S_LifeExp)
(20.0, 0.056), (30.0, 0.0438), (40.0, 0.0366), (50.0, 0.0318), (60.0, 0.0279), (70.0, 0.0258), (80.0, 0.0246)
S_DeathFrac_PreRepro = GRAPH(S_LifeExp)
(20.0, 0.065), (30.0, 0.043), (40.0, 0.03), (50.0, 0.022), (60.0, 0.0165), (70.0, 0.0135), (80.0, 0.012)
S_DeathFrac_Repro = GRAPH(S_LifeExp)
(20.0, 0.027), (30.0, 0.0204), (40.0, 0.0147), (50.0, 0.0107), (60.0, 0.00825), (70.0, 0.00675), (80.0, 0.00555)
S_FertControlEffness = GRAPH(time)
(1975, 0.7), (1983, 0.744), (1990, 0.784), (1998, 0.818), (2005, 0.848), (2013, 0.88), (2020, 0.906), (2028, 0.928), (2035, 0.948), (2043, 0.966), (2050, 0.978)
S_Fert_Mult_ChildMort = GRAPH(S_ChildMortFrac_Perc/INIT(S_ChildMortFrac_Perc))
(0.00, 0.41), (0.1, 0.425), (0.2, 0.45), (0.3, 0.475), (0.4, 0.51), (0.5, 0.56), (0.6, 0.615), (0.7, 0.69), (0.8, 0.79), (0.9, 0.89), (1, 1.00)
```

S_Fert_Mult_LifeExp = GRAPH(S_LifeExp)

(0.00, 0.00), (10.0, 0.195), (20.0, 0.385), (30.0, 0.565), (40.0, 0.715), (50.0, 0.83), (60.0, 0.91), (70.0, 0.96), (80.0, 1.00)

S_IncToHealth_Frac_Index = GRAPH(S_OPC_Index)

(0.00, 0.67), (1.00, 0.999), (2.00, 1.22), (3.00, 1.42), (4.00, 1.55), (5.00, 1.65), (6.00, 1.72), (7.00, 1.77), (8.00, 1.81), (9.00, 1.84), (10.0, 1.86)

S_LifeExp_Decr_UrbPol = GRAPH(S_Co2_Ems_Index)

(0.00, -0.026), (0.5, -0.014), (1.00, 0.00), (1.50, 0.017), (2.00, 0.035), (2.50, 0.053), (3.00, 0.077), (3.50, 0.098), (4.00, 0.128), (4.50, 0.155), (5.00, 0.185)

S_LifeExp_Mult_GlbPol = GRAPH(G_Co2_Atm/INIT(G_Co2_Atm))

(0.5, 1.01), (0.75, 1.01), (1.00, 1.00), (1.25, 0.992), (1.50, 0.982), (1.75, 0.97), (2.00, 0.956), (2.25, 0.941), (2.50, 0.922), (2.75, 0.904), (3.00, 0.886)

S_LifeExp_Mult_HServ = GRAPH(S_HServPerCapita_Index)

(0.00, 0.8), (2.00, 1.16), (4.00, 1.37), (6.00, 1.51), (8.00, 1.60), (10.0, 1.65), (12.0, 1.69), (14.0, 1.73), (16.0, 1.75), (18.0, 1.78), (20.0, 1.80)

S_LifeExp_Real = GRAPH(time)

(1975, 57.7), (1980, 60.0), (1985, 61.8), (1990, 63.1), (1995, 63.8), (2000, 64.3)

S_NoOfChild_Mult_OPC = GRAPH(S_OPC_Perc/INIT(S_OPC_Perc))

(0.00, 1.27), (1.00, 1.00), (2.00, 0.777), (3.00, 0.623), (4.00, 0.511), (5.00, 0.434), (6.00, 0.378), (7.00, 0.343), (8.00, 0.308), (9.00, 0.266), (10.0, 0.245)

S_Population_Real = GRAPH(time)

(1975, 2472), (1976, 2522), (1977, 2573), (1978, 2624), (1979, 2676), (1980, 2729), (1981, 2782), (1982, 2837), (1983, 2893), (1984, 2948), (1985, 3004), (1986, 3063), (1987, 3124), (1988, 3185), (1989, 3247), (1990, 3309), (1991, 3369), (1992, 3426), (1993, 3481), (1994, 3536), (1995, 3592), (1996, 3648), (1997, 3704), (1998, 3760), (1999, 3814), (2000, 3867), (2001, 3919)

S_UrbPop_Frac_Real = GRAPH(time)

(1975, 0.292), (1976, 0.296), (1977, 0.301), (1978, 0.306), (1979, 0.311), (1980, 0.316), (1981, 0.32), (1982, 0.325), (1983, 0.33), (1984, 0.335), (1985, 0.34), (1986, 0.345), (1987, 0.35), (1988, 0.355), (1989, 0.361), (1990, 0.366), (1991, 0.37), (1992, 0.374), (1993, 0.379), (1994, 0.384), (1995, 0.388), (1996, 0.392), (1997, 0.397), (1998, 0.402), (1999, 0.406), (2000, 0.411), (2001, 0.415)

S_UrbtionFrac_Mult_CL = GRAPH(S_UrbPop_Frac)

(0.6, 1.00), (0.64, 0.98), (0.68, 0.945), (0.72, 0.875), (0.76, 0.75), (0.8, 0.58), (0.84, 0.375), (0.88, 0.22), (0.92, 0.115), (0.96, 0.045), (1.00, 0.02)

S_UrbtionFrac_Mult_PopDens = GRAPH(S_PopDensity/INIT(S_PopDensity))

(0.00, 0.615), (0.2, 0.63), (0.4, 0.68), (0.6, 0.76), (0.8, 0.875), (1.00, 0.99), (1.20, 1.09), (1.40, 1.17), (1.60, 1.22), (1.80, 1.25), (2.00, 1.26)

S_UrbtionFrac_Mult_UrbEcon = GRAPH(S_OPC_Index)

(0.00, 0.86), (1.00, 0.956), (2.00, 1.05), (3.00, 1.12), (4.00, 1.17), (5.00, 1.21), (6.00, 1.25), (7.00, 1.28), (8.00, 1.29), (9.00, 1.30), (10.0, 1.31)

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