World Models, Resources, and Environment*

by

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INTRODUCTION

Resources are the life-blood of any industrialized civilization, and thus Man has always been concerned with their continued availability. In primitive societies, which basically depended on agricultural products, the total need for raw materials, and also the varieties required, were comparatively modest. Thus, if they ran out of specific materials, or if natural disasters such as droughts and floods threatened their agricultural production, early humans simply migrated to a better locale.

Gradually, with increasing technological developments, Man's need for raw materials increased and became more complex. Thus, in 1974, an advanced industrialized country such as the United States needed over 4 thousand million tonnes of new mineral supplies to sustain its economy and standard of living, and the projection of the U.S. Bureau of Mines indicates that the U.S. demand for raw materials may rise to 11 thousand million tonnes per annum by the year 2000 (Morgan, 1976).

If agricultural products are included, total annual *per caput* consumption of raw materials in the United States is about 20 tonnes (Landsberg, 1976). This figure is about 10% higher than the findings of the President's Materials Policy Commission (1952), more commonly known as the 'Paley Commission'. The increase in Man's requirements of raw materials is contributed to by two principal factors: increase in population and increase in affluence. Whereas, historically, population has been the principal factor in the increasing demand for raw materials, rising affluence is becoming an increasingly important one; thus, for example, approximately 20% of the annual global increase in food consumption can be attributed solely to affluence (United Nations, 1975).

Although available data from developing countries are fragmentary and analyses are incomplete, the general tendency seems to be towards an increasing *per caput* consumption of materials. Naturally, the base from which this consumption is increasing is very low, and it may be many decades† before they can catch up with the existing consumption patterns of the advanced industrialized countries. Thus, even though India's *per caput* steel consumption more than doubled between 1950 and 1970, it is still only a small fraction of the *per caput* steel consumption of the United States. In the past two decades, the rate of increase of use of materials in the developing countries has tended to be greater than the rate of growth of their national products (Mallenbaum, 1973). All existing indicators, including the growth expectations of these countries, show that their share of materials used will continue to increase in the foreseeable future.

RESOURCES ADEQUACY

From time to time throughout history, questions have been raised about the constantly increasing use of raw materials by Man, and whether such a rapid increase will create problems for future generations. In 1798, Malthus published his now famous book, *An Essay on the Principle of Population as it Affects the Future Improvement of Society* (cf. Malthus, 1803), wherein he pointed out that population grows geometrically—that is, exponentially—whereas food supply grows arithmetically. Malthus allowed for the likelihood that there would be some technological developments but thought these would be finite, and would soon be used by the expanding population. Population would continue to grow until checked by starvation and famine. In his later works, Malthus recommended that Man should practice 'self-restraint' in order to avoid such a catastrophic future. In recent years it has become almost customary to equate his name with a gloomy view of the future of mankind.‡

Malthus believed that human beings multiply geometrically, but that herrings do so only arithmetically. In the twentieth century, there have been several neo-Malthusian writings. Hotelling (1931) summarized the

*Note:—opinions expressed are those of the Author, and not necessarily of any Government, Institute, Agency, or Society, with which he is associated.

†A referee comments that the suggested 'several decades' seems much too short.—Ed.

‡In all fairness, it should be pointed out that the simplistic aphorisms of Malthus's contention that are now attributed to him, do not do justice to the complex theories which he put forward. As is the case with almost any human being, Malthus's ideas developed with time. Even though he is generally known, and blamed, for the opinions on population which he expressed in his 1798 book, a later work entitled *An Essay on the Principles of Population; or a View of its Past and Present Effects on Human Happiness; with an Inquiry into our Prospects Respecting the Future Removal or Mitigation of the Evils which it Occasions*, is much more scholarly. This book of 610 pages was first published in 1803, and was subsequently revised by Malthus in 1807, 1817, and 1826. For a comparative analysis, *see* the introduction by Anthony Flew (1970) to Malthus's *Essay*, published by Penguin Books, Harmondsworth, England.

Environmental Conservation, Vol. 6, No. 1, Spring 1979—

situation admirably in an article entitled 'The Economics of Exhaustible Resources', which could very well have been written today. He said:

> 'Contemplation of the world's disappearing supplies of minerals, forests, and other exhaustible assets, has led to demands for regulation of their exploitation. The feeling that these products are now too cheap for the good of future generations, that they are being selfishly exploited at too rapid a rate, and that in consequence of their excessive cheapness they are being produced and consumed wastefully, has given rise to the conservation movement.'

Similar questions were re-raised in a dramatic fashion by a report entitled 'Blueprint for Survival' by *The Ecologist* (1972), and were later reinforced by another report (Meadows *et al.*, 1972), entitled *The Limits to Growth*, sponsored by the Club of Rome. Both these reports were based on the fundamental and indisputable fact that exponential growth in a finite environment cannot continue indefinitely. Of these two reports, *The Limits to Growth* is of more interest here for the following two reasons: (1) it was the first major global model which encouraged other modellers to develop similar models of world *problematique*—if only to prove that Meadows *et al.* were wrong; (2) this highly condensed but well-written report analysed for the first time the complex interactions between population, resources, and environment, by extensive computer modelling. In so doing it provided a bandwagon for parties who were already more than convinced that mankind was headed straight for disaster, unless growth-oriented policies were forsaken. Whatever the merits or demerits of the major conclusions of *The Limits to Growth* may be, one must admit that it was the first comprehensive attempt to analyse global resources and the future of mankind within a systematic framework.

GLOBAL RESOURCES–ENVIRONMENT MODELS

Beginning with the presentation of *The Limits to Growth* model by Meadows *et al.* in 1972, a series of global models have appeared, emphasizing different aspects of the world *problematique*. Among the major such models pertaining to the population–resources–environment sectors are the following:

1. *Limits to Growth Model* (Meadows *et al.*, 1972). This model was sponsored by the Club of Rome and was based on the Systems Dynamics technique developed at MIT (Forrester, 1971). It was a highly aggregated model that treated the world as a single unit, and primarily consisted of a set of differential equations having simultaneous linkages. These equations were grouped under five major sectors—technology, population, nutrition, natural resources, and environment. The model emphasized the dynamic nature of the world system, and the dependent variables were primarily rates of change-of-state variables, such as population or mortality. The data-base for the model left much to be desired, and some of the data used have been seriously questioned.
2. *Strategy for Survival Model* (Mesarovic & Pestel, 1974). Also sponsored by the Club of Rome, this model used multilevel, hierarchical systems theory, which involved the incorporation of sub-models from different disciplines into one heterogeneous system. It divided the world into ten 'homogenous' regions—U.S.A. and Canada; Western and Southern Europe (including Turkey); Japan; South Africa and Australasia; Eastern Europe (including USSR); Latin America; North Africa and the Middle East; rest of Africa; South and South-East Asia; and Centrally Planned Asia. For each region, a simple sub-model related food production with crude birth- and death-rates. A detailed energy sub-model considered energy availability and demand patterns. An environmental sub-model considered pollution from different levels of production. Other natural resources were not analysed.
3. *Slimlink Model* (World Bank, 1975). This model is concerned primarily with developing countries—especially their future prospects for growth and development (including commodity-trade policies) under alternative patterns of growth and rates of inflation in the industrialized countries. The model represented forty-seven developing countries, which in total account for 76% of GNP and 70% of exports of all developing countries. The developing countries were grouped into seven regions; South Asia; East Asia; East Africa; West Africa; the Mediterranean; Latin America; and mineral producers. The Western countries were divided into three groups: North America, Western Europe, and Japan–Oceania. Eastern European countries were not considered. Individual models for eleven basic commodities were available—iron ore, copper, tin, rubber, rice, sugar, beef, cocoa, tea, coffee, and fats and oils. The rest of the commodities were grouped under the following models: food, agricultural non-food, and metals and minerals.
4. *Latin American World Model* (Bruckmann, 1976; Herrera, 1976). Developed by the Bariloche Foundation in Bariloche, Argentina, and sponsored by the International Development Research Centre (IDRC), of Ottawa, Canada, the model divides the world into the following four regions: all developed countries (OECD countries, Eastern Europe including the USSR, rest of Europe, and Israel), Latin America, Africa, and Asia. For each regional economy, five sectors were considered: agriculture and nutrition, education, housing, capital goods, and other consumer goods. The outputs from the first three sectors were considered to satisfy the basic human needs, which were defined as absolute *per caput* needs of the following:
   - —3,000 calories per day;
   - —100 grams of protein per day;
   - —98% of those aged 6–8 years receive 12 years of education; and
   - —one house (four small rooms) per family.

   These four factors were included in a sub-model

TABLE I. *Comparison of World Models for A.D. 2000.*

Models	*Population*	*Energy and Minerals*	*Agriculture*	*Environment*
Leontief	Exogenous[(a)]	Detailed analysis	Detailed analysis	Detailed analysis for pollution control
Bariloche	Endogenous	–	Simplistic	–
Mesarovic & Pestel	Endogenous	Good energy analysis, no mineral sector	Simplistic	Simplistic
SARUM	Exogenous[(a)]	Contains both energy and minerals sector	Good agricultural sector	–
SLIMLINK	–	Considers iron ore, tin, and copper	Considers only for developing countries	–
MOIRA	Exogenous[(a)]	–	Good analysis of food demand	–
Limits to Growth	Endogenous	Considers reserves and use-rates for energy and minerals	Simplistic	Considers environment and quality of life and has sectoral feedbacks

[(a)]Uses U.N. population estimates; exogenous = produced from outside (as opposed to endogenous = from inside).

that predicted life-expectancy at birth. The model allocated capital and labour resources to five sectors of the economy in order to maximize the objective function—the life-expectancy at birth. It was thus a normative model of the world development process which considered radical changes in the present status of international politics, social institutions, and economic relations.

5. *MOIRA Model* (Linnemann, 1976). Developed at the Free University of Amsterdam, this is basically an agricultural model that considered the agricultural sector in 106 countries, and aggregates agricultural output to 'consumable protein' equivalent. Growth of population and developments in non-agricultural sectors were considered to be exogenous (produced from outside). The econometric model attempted to explain food production as a function of the size of the agricultural labour force, of prices of alternative means of production, of climatic conditions such as precipitation and temperature, and of the prices of food output.
6. *SARUM Model* (Hoogh *et al.,* 1977; Roberts [of the Department of the Environment, U.K.], in press). Developed by the Systems Analysis Research Unit (and hence known as SARUM), this is a highly aggregated macro-economic model having its primary emphasis on agriculture. It divides the world into three strata, depending on *per caput* GNP. The first stratum is the United States, the second stratum consists of all countries having annual *per caput* GNP in 1968 of between $3,500 and $650, and the third stratum includes all countries with *per caput* GNP below $650 per year. The model identifies thirteen productive sectors: capital goods, non-food consumer goods, minerals, primary energy, irrigation, land exploitation, agricultural services, non-food crops, cereals and roots, unprocessed meats, processed meats, processed vegetables, and other vegetables and fruits. It also analyses effects of land, minerals, and energy, depletion, and their consequences on potential production.
7. *Future of the World Economy Model* (Leontief *et al.,* 1977). This is an input–output model that analyses the linkages between economic growth, resources availability, and pollution abatement. Sponsored by the United Nations, it divided the world into fifteen regions—eight from developed countries and the rest from 'developing' nations. The developing countries are divided into two groups, depending on the availability of important natural resources. Either investment or output must be specified exogenously. The model contains 48 sectors: 4 from agriculture, 9 from the mineral industry, 22 from manufacturing, 9 from pollution abatement, and one each from utilities, construction, trades and services, and transport and communications.

GLOBAL MODELS: AN ANALYSIS

It is difficult to compare the results of the global models because of their inherent structural differences and of the original assumptions within which individual modelling frameworks were developed. For example, for a specific model, under different but plausible sets of assumptions, some of its important conclusions could even be reversed (Cole *et al.,* 1973; Cole, 1977). This has been clearly indicated by several investigators in the case of *The Limits to Growth* model.

Table I shows a comparison of world models with regard to their treatment of four different sectors: population, energy and minerals, agriculture, and environment. Table II shows the population and GNP (Gross National Product) for the year 2000 for three major models—Leontief, Mesarovic & Pestel, and Bariloche. The results should be considered as orders-of-magnitude values that provide interesting intercomparisons, rather than absolute figures.

An interesting sidelight of the results obtained from these models is the comparison with the Lima declaration of UNIDO, sponsored by the so-called 'Group of 77' (currently consisting of more than 110 'developing'

TABLE II. *Intercomparison of Results from Three Models for the Year A.D. 2000.* (Population in millions and GNP in thousands of millions of 1972 U.S. dollars.)

Regions	*Leontief*		*Mesarovic & Pestel*		*Bariloche*	
	Population	*GNP*	*Population*	*GNP*	*Population*	*GNP*
Western Block	994	7,239	916	6,941	1,200	8,160
Eastern Block	447	2,931	402	1,966		
Latin America	620	1,332	597	428	486	783
Asia	3,699	2,830	3,446	1,527	4,021	1,532
Africa	639	187	474	83	651	224
Total World	6,399	14,518	5,835	10,945	6,358	10,699

TABLE III. *Food Scenarios for A.D. 2000.* (The figures from the Leontief and Bariloche models are in calories/person/day, having a ceiling at 3,200; the figures from Mesarovic & Pestel indicate the percentage of calorie needs met by available calories).

Regions	*Leontief*	*Mesarovic & Pestel* (% of needs)	*Bariloche*
Western Block	3,200	247	3,200
Eastern Block	3,200	174	
Latin America	2,950	204	3,000
Asia	2,600	118	3,000
Africa	2,300	135	2,984
World	2,500	154	–

countries), which recommended that 25% of all global production by A.D. 2000 should be in the developing countries.

The following are the model projections for A.D. 2000:

Leontief: 30% (assumed)
Mesarovic & Pestel: 19% (endogenous)
Bariloche: 24% (endogenous)
SARUM: 19% (endogenous)
Lima declaration: 25% (proposed).

This indicates that if the higher-yielding models are valid, given political will, the targets of the Lima declaration could be achieved.

With regard to energy, as indicated in Table I only four models considered this important sector. The Leontief model assumed that oil prices in real terms will double, but enough energy will be available until A.D. 2000 to sustain projected growth-rates. Mesarovic & Pestel concluded that there will be a shortage of hydrocarbons, but nuclear energy will make up the shortfall, especially in the developed countries. *The Limits to Growth* model was very pessimistic of the future energy availability. Thus, overall model projections ranged from the relative optimism of Mesarovic & Pestel to extreme pessimism in the case of Meadows *et al.*

Similar variations can be noticed in the agriculture (i.e. food) sector as shown in Table III. Both Bariloche and *The Limits to Growth* models projected somewhat optimistic results to the year 2000, but the situation deteriorated after that time. According to the Bariloche model, the situation in Asia will start to deteriorate after the year 2000 owing to continuing increases in population and the exhaustion of non-cultivated arable land reserves. The overshoot and collapse projected by *The Limits to Growth* model is due to rapidly increasing pollution, as well as to land degradation and the exhaustion of reserves of arable land.

The Mesarovic & Pestel model is pessimistic about the future of both Asia and Africa by the year 2000. It projects 9 million starvation deaths in Asia alone by 2000, and a cumulative total of 550 millions by 2025—a wholly depressing figure. It should be noted that any figure below 140%, as shown in Table III, indicates starvation deaths due to maldistribution of food. The Leontief model indicates a low average calorie intake of 2,600 per person per day in Asia and 2,300 in Africa, but the consequences of such low calorie intakes are not discussed.

Only the Leontief and *The Limits to Growth* models consider the environmental sector seriously. The latter model projects the catastrophic consequences of environmental pollution unless immediate countermeasures are taken. The Leontief model analyses environmental pollution far more rigorously. However, its approach is the rather narrow one of pollution abatement rather than environmental management.

As mentioned earlier, economic activity in each region of the Leontief model is divided into 48 sectors, five of which are concerned with pollution abatement. These are: air pollution control, primary, secondary, and tertiary treatment, and solid-waste disposal. The economic activities generate eight types of pollutants—pesticides, particulates, biological oxygen demand (BOD), nitrogenous water pollution, phosphates, suspended solids, dissolved solids, and solid wastes. For each productive activity, emission coefficients are defined, which indicate quantities of pollutants in metric tons per production unit of each economic sector. The level of pollution abatement activities are also expressed in metric tons treated. As data availability on a global basis leaves much to be desired, the emission coefficients in various regions of the world are based on those of the United States, with some minor adjustments.

The model uses four abatement scenarios depending on GDP* *per caput* as shown in Table IV. Table V shows the assignment of regional abatement scenarios.

The volume of capital stock necessary for abatement in different regions and over different time-horizons is shown in Table VI, which also shows the total original capital stock that may be used for pollution control.

*GDP = Gross Domestic Product.

TABLE IV. *Abatement Scenarios of Leontief Model*

Regions having GDP per caput	*Abatement scenarios*
1. Less than $700	No abatement
2. Between $700 and $2,000	Half of abatement of USA in 1970
3. More than $2,000, but less than $2,000 in preceding period	Same abatement as in USA in 1970
4. More than $2,000, and also more than $2,000 in preceding period	Net emission held at absolute levels reached the year USA standards were first applied

TABLE V. *Assignment of Regional Abatement Scenarios*

Regions	*1970*	*1980*	*1990*	*2000*	*Average annual growth-rate (%)*
North America	3	4	4	4	3.3
Latin America (Medium)	1	2	2	2	7.1
Latin America (Low)	1	1	1	2	7.2
Western Europe (High)	3	4	4	4	3.7
Western Europe (Medium)	2	2	2	3	7.0
U.S.S.R.	2	3	4	4	5.2
Eastern Europe	2	3	4	4	4.9
Asia Centrally Planned	1	1	1	1	6.3
Japan	3	4	4	4	4.9
Asia (Low)	1	1	1	1	6.7
Middle East	1	2	2	3	9.0
Arid Africa	1	1	1	1	5.5
Tropical Africa	1	1	1	1	6.5
Southern Africa	2	2	2	2	7.5
Oceania	3	4	4	4	4.5

For example, for North America it progressively declines from 3.4% in the Seventies and Eighties to about 2.5% in the year 2000. For Japan, it increases from 2.8% in 1970 to 3.9% in 2000.

The Leontief model examines two major pollution-related problems:

—is increase in pollution inevitable? and,

—are abatement costs unrealistically high?

The report concludes that many of the present emissions can be significantly reduced, and the total cost of pollution abatement would be around 1.4 to 1.9% of GDP. If the emission standards were lowered, the costs would be further reduced to around 0.5 to 0.9% of GDP. With regard to capital stock, the ratio is larger, being around 5 to 8% of total national capital stock when all abatement activities are considered.

These indications, like any others generated from the world models, should be treated with some degree of caution. While the Leontief model considers the pollution abatement sector more satisfactorily than any other world model, direct information from this model cannot be used in an operational sense. It does, however, clearly indicate that pollution can be controlled at a reasonable cost, without endangering future economic growth. This finding is consistent with experiences from North America.

WORLD MODELS AND THE FUTURE

A detailed analysis of *The Limits to Growth* model, six years after it was published, makes it look even weaker than it did at that time. It has too many shortcomings, the principal ones being the following:

(a) The degree of aggregation was too great to simulate the world *problematique* realistically;

TABLE VI. *Capital Stock of Abatement Sector (CAB) in thousands of millions of dollars, and its share in Total Capital Stock (%CT).*

	1970		*1980*		*1990*		*2000*	
	CAB	*%CT*	*CAB*	*%CT*	*CAB*	*%CT*	*CAB*	*%CT*
North America	77.5	3.4	121.9	3.4	156.0	3.0	191.7	2.5
Latin America	0.0	0.0	4.3	1.5	8.8	1.3	38.4	2.3
Latin America (Low)	0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.0
Western Europe (High)	35.9	2.7	67.2	3.2	107.9	3.1	160.6	3.2
Western Europe (Medium)	1.2	1.1	2.4	1.1	5.6	1.1	21.3	1.8
U.S.S.R.	9.9	1.3	38.9	2.8	87.4	3.1	125.3	2.6
Eastern Europe	3.5	1.2	13.8	2.7	28.8	3.1	40.8	2.9
Asia Centrally Planned	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Japan	8.6	2.8	23.7	3.6	45.9	3.9	70.0	3.9
Asia (Low)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle East	0.0	0.0	1.9	1.2	0.0	0.0	39.8	1.9
Arid Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tropical Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Southern Africa	0.3	0.9	0.6	1.2	1.3	1.1	5.8	2.0
Oceania	1.7	2.1	4.0	3.1	8.9	3.6	10.4	2.5

(b) The data-base was inadequate, and the veracity of data inputs left much to be desired;
(c) The modelling methodology contains errors, and the model was too mechanistic;
(d) The resources and reserve figures assumed were pessimistic, and interactions between prices and reserves were not seriously considered;
(e) Technological developments were not considered, and yet over a longer time-horizon these would undoubtedly have major societal impacts; and
(f) Physical aspects of world *problematique* were emphasized, but sociological and institutional aspects were neglected.

One of the main projections of the model indicates that population and economic growth should cease by the year 2000; otherwise the society would overshoot and collapse. As all present evidence indicates that it is unlikely that population and economic growth are going to level off by the year 2000, it basically gives mankind two options: either to eat, drink, and be merry (that is, those fortunate enough to be able to do so!) until the society and economy collapse, or else to commit suicide, because no matter what countermeasure is taken, society is going to collapse anyway, though there might be some possibility of delaying the doomsday.

The Limits to Growth model made a profound impression on many people concerning the effects of exponential growth. However, any person having a modicum of mathematical training and an abacus (a computer is *not* necessary), can easily show that exponential or even linear growth within a finite space cannot continue indefinitely. For example, if population growth is considered at an average annual rate of 2%, the world population will increase to 6.6 thousand millions by A.D. 2000, to 18 thousand millions by A.D. 2050, to 48 thousand millions by A.D. 2100, and to 344 thousand millions by A.D. 2200. Obviously, the world does not have a resources-base to support 344 thousand million people: growth would be curtailed by one means or another well before any such figure could be reached. Furthermore, such aggregated global population figures do not provide a true picture, as regional implications could be far worse. Thus, a fourfold increase in total population, under the current growth-rates, would amount to a tenfold increase in the population of Africa. Consequently the real reason is not whether there is some limit to population growth, because there is, but the estimates of this limit under different socio-economic scenarios. We also need some indications of the time-horizons when such changes can be expected, and their differential effects on the various regions of the Earth.

The Limits to Growth model sparked off a lively debate on the issues of resources exhaustion, environmental degradation, and societal collapse. Some people supported the findings strongly, and others opposed them equally strongly. The opponents suggested that all doomsday projections are nothing but nonsense and 'science fiction' (Beckerman, 1972; Maddox, 1972). They basically concluded that 'mankind will go on bumbling along in the same way as he has done before'. There certainly are serious problems ahead, many of which are age-old problems such as poverty, disease, prejudice, crime, inequality, population, etc., which Man should be able to handle. Beckerman even suggested that a 'Club of Athens' of the 5th century B.C., using similar facts and techniques as the Club of Rome, could have predicted that the world was heading for disaster. By extrapolating the trend of timber shortages and pointing to the over-population of Athens, such a 'Club of Athens' could have concluded that they must renounce growth and give up hope of providing everyone with a timber house, a bronze statue of Poseidon in the back garden, and a white-ground Lethykos on the mantlepiece!

DANGERS OF PROJECTIONS

Scenarios of certain futurists, such as Herman Kahn, of course are very different. He has continuously predicted (e.g. 1976) that a far rosier picture awaits the future of mankind. Such scientists have often exuded unbridled optimism and tend to deny the existence of any limits. Closely scrutinized, however, their optimisms contain enough qualifications to account for most eventualities. For example in his latest book, *The Next Two Hundred Years,* Kahn (1976) predicted that the human population will stabilize at about 15 thousand millions—give or take a factor or two, which means somewhere between 7.5 and 30 thousand millions! But whereas it seems quite likely that the global population may stabilize somewhere between these two figures, it makes the most profound difference in terms of policy formulation for the future of mankind whether it is 7.5 thousand millions or four times that estimate; the implications are almost entirely different!

The truth in this controversy probably lies somewhere in between the two extreme viewpoints. If one considers the present energy crisis, it is certainly not the first one that mankind has faced. There was at least one before—around 1865 to 1867. Up until that period, a major energy source for artificial lighting in North American and Europe was whale oil. Since other adequate alternative sources of energy were not available, artificial lighting depended very extensively on the whaling industry. As was implied earlier, one really did not need a sophisticated mathematical model to predict that there just were not enough whales in the world to satisfy the rapidly burgeoning demand for whale oil. Since the supply did not keep pace with demand, the price of sperm-whale oil rose from $0.43 per gallon* in 1823 to $2.55 in 1866, and other whale oil rose from $0.23 per gallon in 1823 to $1.45 in 1865 (Biswas & Biswas, 1976).

Besides the price increases, there is another similarity between history's two 'energy crises'. Like the recent one which was precipitated by the Middle East war, the

*1 U.S. gallon = 3.785 litres. 1 Imperial gallon = 4.546 litres.—Ed.

first energy crisis was precipitated to a considerable extent by the American Civil War, which not only increased the demand for these types of oil, but also seriously disrupted their production and distribution. Some of the whaling ships were conscripted and others were captured or destroyed by the Southern confederates. Consequently, the number of American whaling ships declined by more than 50%, and the total tonnage by more than 60%.

The scarcity of these whale oils and the resulting price increases brought a whole set of new forces into play. There was a growing incentive to develop new alternatives to these products, and this created new investment which accelerated the rate of search for alternatives. New technology was developed which made it economical to produce gas from coal in Europe. By 1867, new refining processes made it economical to refine kerosene from crude petroleum. These two technological developments, in Europe and North America, solved the first energy crisis. They also made whale-oil lamps antiques by 1896, and reduced the price of sperm-whale oil to $0.40—cheaper than it had ever been in any earlier recorded period.

The above example is cited to indicate that many of the latter-day Cassandras have significantly under-estimated the power of technological developments and economic market forces that come into play in a resource-scarce society. This, however, does not mean that the other extreme school of thought, which categorizes increasing resource consumptions as problematical to say the least, is correct either.

THE 'NO BIG DEAL' SCHOOL

This school suggests that, as resources are used more and more, they become scarce, and thus create economically negative feed-backs—that is, increasing scarcity of any resource would lead to an upward trend in its price which, in turn, would provide the necessary incentives for new exploration, further recycling, and development of substitutes. In other words, resource scarcity and the resulting economic forces would provide the necessary stimulus to technological developments, which would solve the problems in time.

The second major point of the argument of this school is that, even though the resources of the Earth are finite, technological developments have so far made it possible and profitable to seek new reserves and develop them. The Russian Academician E. K. Fedorov (1974) has suggested that these developments have made it possible for the proven reserves to grow 'all the time, both in total figures and in *per capita* terms'. Beckerman (1974) has stated:

> 'Total natural occurrence of most metals in the top mile of the Earth's crust has been estimated to be about a million times as great as present known reserves. Since the latter amount to about a hundred years' supplies, this means we have enough to last about one hundred million years. Even though it may be impossible at present to mine to a depth of one mile at every point in the Earth's crust, by the time we reach A.D. 100,000,000 I am sure we will think up something.'

In other words, have faith in technological developments: they should solve all the problems of mankind!

There are several flaws in these types of arguments, and only the major ones will be briefly discussed here. First, it is a fact that technological developments have improved explorational and extraction practices in the past. For example, the average grade of copper mined in the United States has fallen from 1.6% in 1936 to 0.65% in 1971, as shown in Fig. 1. Also, as the price of copper has increased, there has been more and more substitution as one would expect. The problem of extrapolating this type of reasoning is that, while it may be possible to take in our stride one, or up to a few, select resource shortages, our capability for taking care of widespread shortages, whether natural or man-made, or of several resources simultaneously, is very dubious. We should certainly not take such capability for granted.

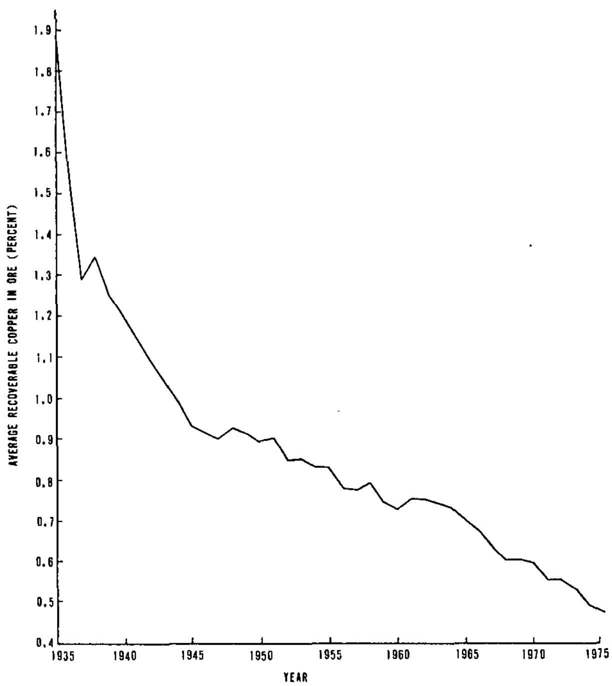

Fig. 1. *Average recoverable copper in ore (%), United States of America 1935–75.*

Technological developments are not cheap: they need substantial capital investment. Thus, if the total costs of technological developments to devise alternatives for resource shortages, as well as the costs of alleviating the problems of hunger, malnutrition, diseases, regional disparities, inequalities, housing, education, etc., both nationally and internationally, are added up, the richest countries of the world, or even groups of such countries, would not have enough capital to pay for a significant percentage of the costs. As the productive capacity of a society is limited, its available investment capital is also limited. Since research and technological developments are direct functions of available capital, the extent of their effectiveness in devising new alternatives is also limited. Hence, mankind must not put all its trust in technological development, hoping that the distant future, which none of us will live to see, will be bright and beautiful even though the present is full of hazards and uncertainties.

The second problem is that nearly all the technological innovations which have contributed in the past to the development of lower and lower grades of resources, have been made possible by the increasing use of cheap and abundant energy. The 'rules of the game' have now been drastically changed: energy is no longer abundant, and the era of cheap energy is long past. It has been suggested that breeder reactors will make 'limitless' energy available in the future, but even if breeder reactors become a reality and acceptable to society as a whole, energy will certainly not be cheap. Thus, energy-intensive alternatives cannot be depended on *ad infinitum* to bail us out of our complex problems.

The third consideration, of course, is that of environmental constraints. As more and more low-grade resources are used, more residuals are created which have to be disposed of in environmentally-acceptable fashions. This relationship can change if recycling processes are stepped up; but 100% recycling is not economically feasible or indeed possible, and hence, after some time, the point of diminishing return would be reached. There is, however, no doubt that we have quite far to go before such a point is reached.

Thus, looking at the whole scenario objectively, it is hard to share the views of the latter-day Cassandras who say that mankind could hardly survive the next hundred years, or the views of the high priests of technology whose unbridled optimism would have one believe that market forces should precipitate suitable technological developments at every stage, whenever they are needed. However, based on present analyses of the socio-economic conditions and institutional infrastructure of different regions, one tends to be somewhat pessimistic.

CONCLUSIONS AND SUMMARY

World models are still in the early phases of development, and the majority of the ones built so far do not deal with the resources and environment sectors adequately. Of the models available, only the Leontief input–output model considers these two sectors in some detail. Even then the results should be taken as orders-of-magnitude guesses rather than as figures that can be used in an operational sense. Furthermore, the Leontief model suffers from a basic defect: it is a pollution abatement model. From the resources and environmental standpoint, it would be much more preferable to consider this as a sector within an overall management framework in which pollution control could play an important part.

Modelling of world *problematique* is still in an early stage of development, and much work remains to be done to improve its basic structures, underlying assumptions, and data availability. Because of the difficulties—both conceptual and practical—many important areas are not considered in the resources and environment fields, or, if considered, are dealt with only superficially. An example is the consideration of the extent of recycling, conservation, and materials substitution, as prices of individual resources increase—owing either to economic market forces or man-made factors. While the general direction of the main thrusts are known, it is still difficult to define limits and determine interlinkages with any high degree of confidence. Much further work will be necessary to establish these interrelationships, the components of which will also need to have an adequate data-base.

These facts, however, do not mean that world models do not have a role to play. Indeed, within five years of the appearance of the first such model, they have already contributed to a better understanding of the world *problematique*. They have often initiated debates on the interrelationships between major world problems, on both global and regional bases, and thus have contributed to our understanding of these complex interactions. For example, the contributions of both *The Limits to Growth* and the Mesarovic & Pestel models to the consideration of alternative life-styles have been substantial and are indeed immeasurable. There is no reason to doubt that, as world models continue to become more and more sophisticated, they will give increasing insight into the complex interdependencies among the components which shape the destiny of mankind.

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The United Nations University and its Programmes

On 6 December 1973 the UN General Assembly unanimously approved the Charter of the United Nations University. From its inception it was intended that this should mobilize the international academic community to work towards the solution of the many problems plagueing the modern world.

Since the opening of the UN University centre in Tokyo, the University has been under the direction of Rector James M. Hester, formerly President of New York University. This centre is the University's central planning and coordination point from which it operates through the beginning of what will eventually be a world-wide network of institutions and scholars.

This new member of the UN family is unusual for anything calling itself a university, as it has no campus, students, or degree courses. Rather, it was founded to organize outstanding scientific and scholarly collaboration to help identify and alleviate pressing global problems of human survival, development, and welfare. Therefore it invites specialized institutions and scholars to help identify critical international problems, to undertake internationally-coordinated research and advanced training, to strengthen research and advanced training resources in developing countries, to disseminate the research results both to scholars and decision makers, and to encourage problem-oriented multidisciplinary research and advanced training. Thus, the lecture halls and laboratories of the UN University are being spread throughout the world in order to provide opportunities for scholars from developing as well as industrialized nations to undertake research and advanced training towards surmounting these pressing problems.

Autonomy Necessary

In order to guarantee its financial independence and academic freedom in the choice of subject matter and participating institutions and individuals, the UN University was set up not as an intergovernmental organization but as an autonomous academic institution under the sponsorship of the UN and the UN Educational, Scientific and Cultural Organization (UNESCO), with its own endowment fund.

The University's autonomy is necessary in order to stimulate the highest scholarly and objective examination of problems which are often marked by political and social controversy. In its operation the UNU is composed of the members of its governing Council, the Rector and headquarters staff, the Programme Advisory Committees, the research and training staff of Associated Institutions and research units, and participating scholars and Fellows appointed for advanced training.

The headquarters of the UN University were located in Japan after that nation generously provided an initial pledge of $100,000,000 to this Endowment Fund. Other nations of the world, too, are beginning to make important pledges to this Fund—notably the United Kingdom and Venezuela, which have each pledged $10,000,000, and Saudi Arabia and Sudan, which have each pledged $5,000,000.

Formulation of the general principles and policies is the responsibility of the Council which is composed of 24 members who serve in their individual capacities and are drawn from a broad geographical, academic, scientific, and cultural, basis.

The more detailed programme activities of the University have been developed in consultation with Advisory Committees, made up of leading scientists and other scholars from the academic community. In the formulation and implementation of the University's programmes and projects, special care is taken to involve other UN organizations and specialized agencies, in order to avoid duplication and promote activities which complement those of other international bodies.