J. ENVIRON. SYS., Vol. 1(2), pp.133-152 , June, 1971

A Macrosystem Analysis of the Human Environment

DR. KAN CHEN
Professor of Environmental Systems Engineering and Electrical Engineering
University of Pittsburgh

ABSTRACT

There is a need for macrosystems analysis of the human environment on a global basis. Such an analysis would provide a framework for integrating the proposed solutions by engineers, economists, futurists, and other professionals who have taken global and future-oriented views of the environmental issues. As an example, an initial framework for policy research on population and environment is proposed.

The World Macroproblem

The widespread debate on environmental issues indicates the universal recognition of the existence of what many have come to call the *world macroproblem.* Although there is no precise definition of the problem, its ingredients are usually perceived to include the exploding growth of population, technology, and economy, and the resultant pressure on ecology, natural resources, and all aspects of the human environment. Of course, these ingredients of the problem have existed throughout man's history, and somehow mankind has survived and prospered. However, there are reasons to believe that we face certain unprecedented environmental issues. In a nutshell, the major issues are that, for the first time in man's

The work on this paper was partially supported by a grant from the Alfred P. Sloan Foundation.

doi: 10.2190/WX6C-5TY6-NH57-1Q2R
http://baywood.com

history, we may not be able to overcome the macroproblem mainly through *technology*, and we may be running out of *space* and *time*.

Arnold Toynbee considers technology as "the field of mankind's most brilliant successes in history."[1] Thomas Malthus' prediction of disaster was proven wrong by new resources and new technology. However, to wield its power, technology has to draw from our natural resources and environment. Serious questions have been raised as to whether we are running out of open space, clean air, and clean water–whether technology can circumvent the limit of our environment. While technical solutions probably will be found to create new energy and new materials, these very solutions may make our polluted environment worse. It is not clear whether technical solutions can keep our air and water clean while creating new energy and resources for mankind.[2]

In the past, new frontiers for expansion could always be found. The accelerating growth of population and technology, however, has shrunk the world. As Robert North put it, "we have never before lived in anything like the kind of world we live in now. Before, tribes had been buffered from each other, but now we are all living 'cheek to jowl.' "[3] The picture of the earth taken from outer space has greatly impressed on the public the notions that the planet earth is but another spaceship, and that the biosphere is a relatively thin and vulnerable shell.

While the public awareness of limited space on earth has been greatly increased, apparently the notion that we may be running out of time in solving the world macroproblem has not so far made an equally strong impression. Many, if not most, of the people living in an affluent society would feel that the most disastrous consequences of the unsolved world macroproblem will not be with us in the foreseeable future–at least not within our lifetime. However, a recent comparative study by Austin, Brewer, and their students[4] shows a very interesting projection of world population. (See Fig. 1.) Although the world will not come to an end at the theoretical "doom time" of 2027 A.D., Austin and Brewer concluded that a catastrophe on a scale many times greater than that of World War II is bound to happen unless a massive population control program becomes effective before that time. The year 2027 seems to be remotely distant. Most "long-range" plans stop at the year 2000 (we may become victims of round numbers). However, the young people today can expect to live beyond 2027; and, with the rapid development in biological and genetic controls, there is an increasing probability for middle-aged Americans to live long enough to see and experience the most disastrous consequences of the world macroproblem within their lifetime!

Need for Macrosystem Analysis

A great deal of public pressure and crusading spirit to restore our environment has been generated recently by numerous books,[5] editorials, television programs, and action programs such as the national environmental teach-in.[6] The United States as a nation appears to be ready and willing to deal with the world macroproblem at the policy level, as evidenced by the establishment of the President's Council on Environmental Quality, the Environmental Protection Agency, the Commission on Population Growth and The American Future, and many counterparts of these new agencies in the state and local governments. As environmental

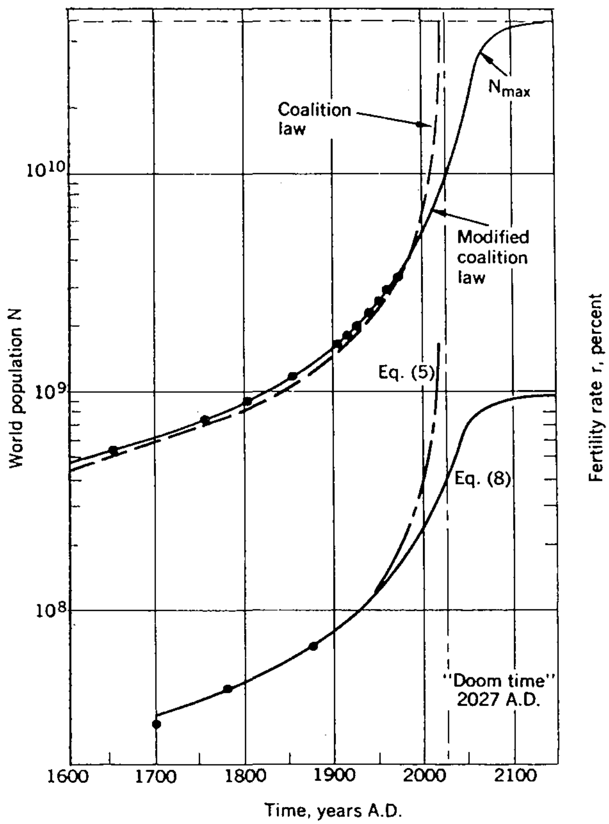

Figure 1. World population trend. (from Reference 4)

problems recognize no political boundaries, the discussion on environmental issues is gathering a great deal of momentum in the United Nations.[7] With so much talk about environmental issues these days, one would blanch at the thought of adding another article that could contribute anything to this area.

On the other hand, much of the debate on environmental issues appears to be charged with emotion rather than rationale, and the drastic actions proposed by the more forceful advocates tend to be based less on step-by-step reasoning. Careless and oversaturating accusations are likely to induce unnecessary backlash that does not help solve the problem. Excessive alarms may lead us to the conclusion that since there are too many kinds of environmental threats to beware of, we may as well ignore all of them. There is a need for defining precisely the scope of the environmental problem and for ordering the priority of all related programs at the highest level of our government.[8] Presently, if we try to distill meaningful concerted actions from the debates, we can find few action-oriented policies that are generally accepted and can measure up to the magnitude of the world macroproblem. Although a number of advanced thinkers have taken global and future-oriented views of the environmental issues, their views tend to represent their respective professions or disciplines and have not been integrated either for policy decisions or for assessing our progress or retrogress with respect to getting the macroproblem solved.

For the above reasons there is a need for macrosystems analysis of the human environment on a global basis. In the remainder of this paper we shall discuss how several selected engineers, economists, and futurists have tried to analyze the macroproblem, and how their analyses *might* be integrated in a macrosystems framework.

Engineers' Approaches to the Macroproblem

Numerous engineering projects are in progress to develop new devices and new systems for monitoring, controlling, and reducing pollution in our environment. A major effort is being made to reduce pollutants from automobile exhaust. The logic for concentrating on this effort appears sound, considering that 70 per cent of the air pollution in many American cities is attributed to automobile exhaust, that economic loss from physical damage caused by air pollution is allegedly much more substantial than that caused by other forms of pollution, and that, as Allen Kneese put it, "with respect to air pollution we are somewhat in the same position as the fish are in regard to water pollution—we live in it."[9]

While a concerted effort on automobile-caused pollution may lead to major, immediate, and visible improvement of the environment, pollution effects of energy consumption may be a more significant global and long-range problem. Austin and Brewer suggested that perhaps the best index of quality of life is the energy consumption per capita.[4] Looking beyond the year 2000, nuclear energy is most likely to play the dominant role in power production. Assuming that radiation hazards are to remain under control, the most important problem will be thermal pollution from waste heat.* There are two fundamental approaches to alleviate this problem:

1. to increase the overall efficiency of power production and distribution so that the waste heat per unit of energy consumption will be lowered, and
2. to increase the rate of dissipating waste heat from the planet earth.

The first approach includes many new energy conversion and transmission systems whose basic principles have long been known to man and have been put to use in some space and military applications, but have not been developed to be sufficiently economical and practical yet for commercial applications. The second approach has not received much attention. However, in a recent paper, Tsongas, *et al.*,[10] described a conceptual design for a system that is very much in the direction of the second approach. They projected the world energy consumption to the time (around 2050 A.D.) when it approaches 1 per cent of the solar radiation on earth. Thermal pollution will then no longer be just a localized ecological problem, but will profoundly influence the ecology of the entire planet. (Actually, in concentrated areas like the Boston-Washington megalopolis, energy production is projected to exceed 30 per cent of the incident annual solar energy by the year 2000.) The design by Tsongas, *et al.*, would use a radiator (possibly a pond with a diameter of 2.5 miles for a 1000-mw power plant) to radiate waste heat to outer space through the 8- to 10-micron atmospheric "window." This kind of "macro-engineering" design should begin now; the process of reducing it to actual and widespread applications may take decades. The interesting fact that Tsongas, *et al.*, borrowed many of their specific ideas from spacecraft thermal control engineers suggests that our heritage in space technology may find its most significant spinoff by considering earth as the macrocosm of a spaceship.

Another macro-engineering approach would be to consider the flow of energy and matter in our entire techno-economic system, including the

*Other tacit assumptions include that solar energy will not become the major energy source and that the demand for energy will continue to grow.

waste outputs that have zero or negative economic value. Such a flow diagram is shown in Fig. 2, and can be used to stimulate engineering design ideas for the increase of recycling in the total system or for the decrease of waste outputs. This kind of approach will be consonant with the concept of "spaceman economy." The optimization of design will need a quantification of the negative values to be assigned to the various waste outputs. How do we assign disvalues (or charges) to waste outputs? What are the implications of the spaceman economy? Let us turn to the economists for their answers.

Economists' Approaches to the Macroproblem

Perhaps the most basic concept upon which most economists tend to anchor their views on environmental issues is that of externality. When side effects are generated in a production or consumption process, such as the unintentional generation of pollution, "external economies and diseconomies" result, and the market mechanism, i.e., buyer-seller relationship, alone may not produce the best allocation of resources. Ralph Turvey pointed out that there are four ways of dealing with externality:

1. Regulation by public authorities, e.g., prohibiting the use of certain fuels or requiring that effluents be treated;
2. Contract between the party that causes and the party that is subject to external effects, usually with payments by one to the other resulting in maximum total gain or minimum total loss;
3. Taxes imposed by the public authorities at a rate supposedly commensurate to the external dis-economy, or excess of social cost over private cost; and
4. Internalizing the externalities by centralizing decision-making for the group of units whose activities have external effects on each other.[11]

Each of the above four ways of dealing with externality has pros and cons. For example, "effluent charges," a form of taxes on effluents, has the advantage of permitting each polluter to find his "least-cost mix," for example, by joining hands to realize certain economies of scale in large-scale treatment facilities, thereby minimizing the total cost of cleaning up a river.[12] On the other hand, regulations are easy to police and are simple for the public to understand and to put legal and moral pressure on polluters. The choice of the most appropriate way will thus depend on the specific local situation. However, regardless of which way to use, the local actions would be fragmentary and could not convey their sense of urgency and priority unless they are also considered collectively at the macrolevel. The interrelationship among all the production and consumption activities

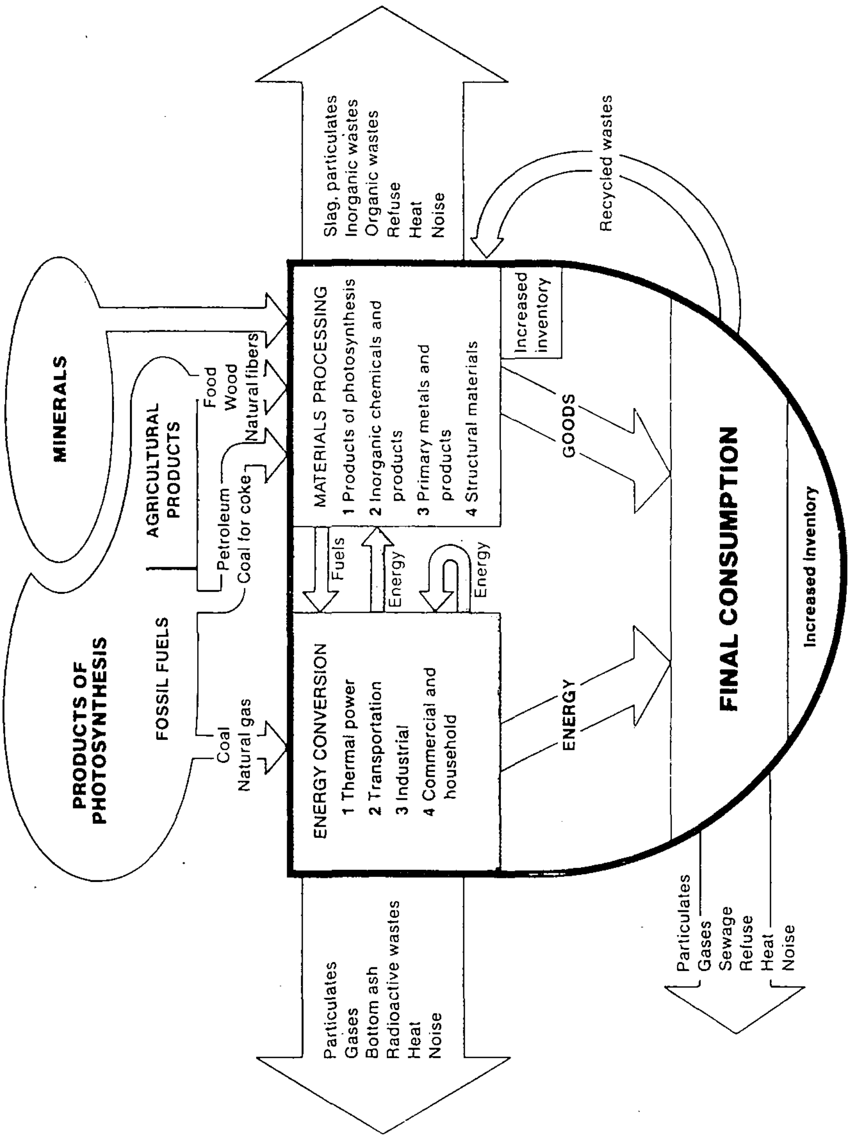

Figure 2. Energy and materials flow in the total techno-economic system. (from Reference 12)

and their side effects on our environment can be quantified through an extension of the input-output economic model.

In a recent paper, Wassily Leontief incorporated the external effects on environment into the input-output model of a national economy.[13] The basic approach is to include *all* outputs (those having negative values as well as those having positive values) of our economic activities in the model. From the standpoint of systems science, it will be desirable to derive Leontief's results graphically from a block diagram, as shown in Fig. 3. In this diagram the variables x's and y's are vectors, and the parameter arrays A's are matrices. Thus, in Fig. 3a, A_{11} is the conventional input-output matrix that deduces the required intermediate products from total products (goods and services) x_1, which must be equal to the sum of intermediate products and final demands y_1. Given the current technology, total pollutants y_2 can be computed from x_1 through the multiplication by A_{21}. Now, instead of accepting y_2 as generated, we may set y_2 at the desired standards and deduce x_2, the total pollutants that must be eliminated to meet environmental standards. (See Fig. 3b.) However, the processes of eliminating x_2 will (1) require industrial products (through a relationship quantified by A_{12}) and (2) themselves generate pollutants (through a relationship quantified by A_{22}). Furthermore, the consumption of final demands y_1 will also generate pollutants (through a relationship quantified by A_y). These added relationships are included in the final block diagram (Fig. 3c). One can write two "cut-set" equations at the two summation points, respectively, as

$$y_1 + A_{11} x_1 + A_{12} x_2 - x_1 = 0$$

$$-y_2 + A_{21} x_1 + A_{22} x_2 - x_2 + y_2^* = 0$$

These two equations may be summarized by the following matrix equation:

$$\begin{bmatrix} y_1 \\ y_2 - y_2^* \end{bmatrix} = \begin{bmatrix} I - A_{11} & -A_{12} \\ A_{21} & A_{22} - I \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

where I is the identity matrix. From such an equation, which describes the external effects quantitatively at the macrolevel, one can predict the effect of any proposed change in technology, be it new technology for eliminating pollutants, new technology for producing goods and services, or new technology for consumption activities. Furthermore, as we optimize the *net* output values for a set of standards y_2, we can impute for y_2 their

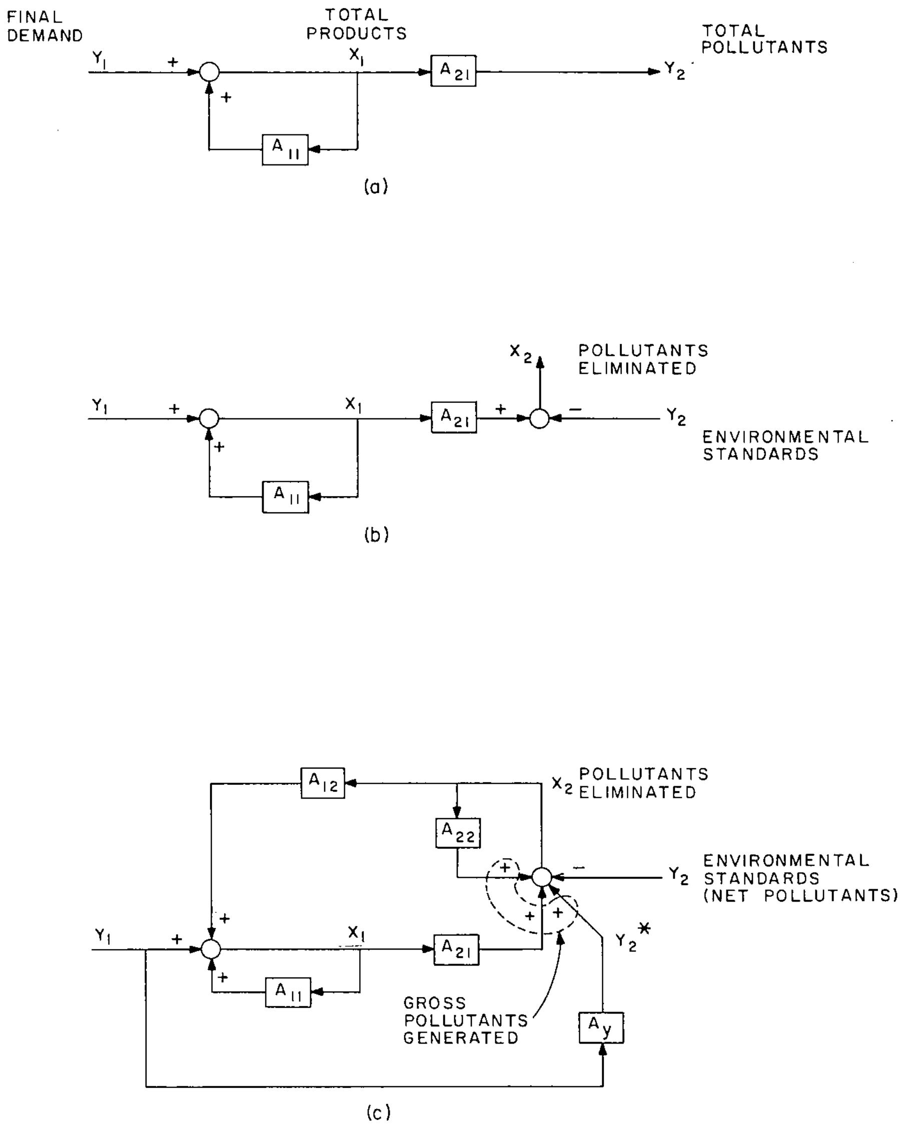

Figure 3. Input-output model including environmental effects.

"shadow prices," which can then be used as a guide for taxes imposed on pollution producers.

While the above procedure appears sound and logical, it is not without practical and philosophical difficulties. First, the task of gathering data for the parameters (the A matrices) is costly and time-consuming. It took a couple of years to obtain and analyze data for A_{21} in a local study project restricted to solid wastes alone.[14] At present, we know so little about the long-range effects of various pollutants that the setting of environmental standards y_2 tends to be more political than scientific. The rapid changes of technology also make the above calculation lose long-term significance. As Arjay Miller testified before the U.S. Congress, "no one really knows how to define in objective terms what we mean by pure air or clean water, or what it will cost to attain these objectives."[15] This lack of data has made the public debate on environmental issues in the context of national goals and priorities very difficult. Furthermore, the final demands y_1, the more important of the two independent variables, depends on the size of population and the populace's desire to consume, the determinants of which are in the realm of social habits, which the economist and the social scientist, according to Barry Commoner, must figure out how to change.[16]

An economist who takes a really global view on environmental issues is Kenneth Boulding, also a social philosopher. Emphasizing the attitude toward consumption, Boulding suggested that we may by necessity be in transition from the "cowboy economy" to the "spaceman economy."[17] In the cowboy economy consumption is regarded as a good thing and production, likewise. By contrast, in the spaceman economy, "the essential measure of the success of the economy is not production and consumption (GNP), but the nature, extent, quality, and complexity of the total capital stock, including in this the state of the human bodies and minds included in the system."[17] If the goals and values in our economic system should take such a turn such as suggested by Boulding, the future use of technology may be quite different. For example, technology may be developed to give us clothes that never wear out, houses that will not depreciate, etc. Is it plausible that we may enter such a world soon? What are some of the alternative futures open to us? Let us now turn to some of the futurists to see what they have to say.

Futurists' Approaches to the Macroproblem

Futurists is a term that has been used to label the people, regardless of their disciplinary backgrounds, who try to analyze seriously the various aspects of mankind's long-term future. Most futurists believe that mankind's future is not predestined and that man has developed unprecedented capabilities to shape his future. With a predisposition for taking a global view of man's problems, like beings from another world viewing the changes on earth, futurists were the first people to identify the world macroproblem. Thus, Aurelio Peccei proposed "Project 1969" as a multinationally sponsored feasibility study on systematic, long-term planning of world scope. The object of planning would be the integrated macrosystem of mankind and his environment.[18]

At the initiation by Peccei and others, the Club of Rome was formed and a project sponsored by the Club has focused on the interacting dynamics of population, pollution, capital investment, natural resources, and quality of life.[19] Figure 4 shows a preliminary computer simulation result based on the initial work led by Dennis Meadows and Jay Forrester.[20] The methodology underlying the simulation followed largely the approach that Forrester had used for the analyses of industrial dynamics and urban dynamics, all of which are characterized by a multiloop, nonlinear feedback system structure derived intuitively and heuristically. Interestingly, the population projection in Fig. 4 peaks out

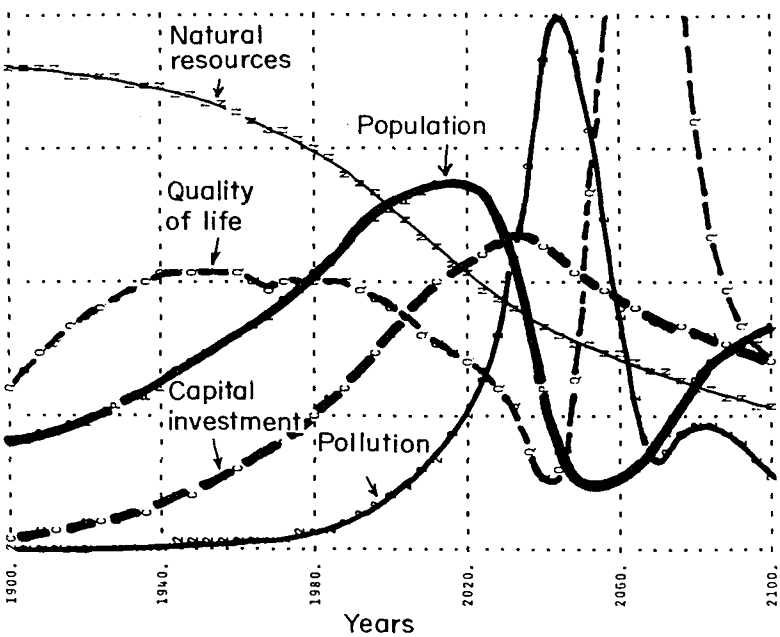

Figure 4. Computer result from a world dynamics model. (from Reference 20)

around the year 2020 (close to the "doom time" of 2027 A.D. given in Fig. 1) when the death rate, influenced by pollution, food, and material standard of living, overtakes the birth rate. Clearly, the world population cannot continue to grow indefinitely but will sooner or later reach an equilibrium. The alleged purpose of the world dynamic model is to improve our ability to consider rationally and productively the implications of current world trends and the options associated with the ultimate transition to global equilibrium.

Another attempt has been made by Willis Harman, *et al.*, to determine the set of feasible alternative futures (primarily for the United States but with worldwide implications) and the transitional stages which we might go through to reach each of the alternatives.[21] The tentative results are summarized in the form of an "alternative futures tree" as shown in Fig. 5.

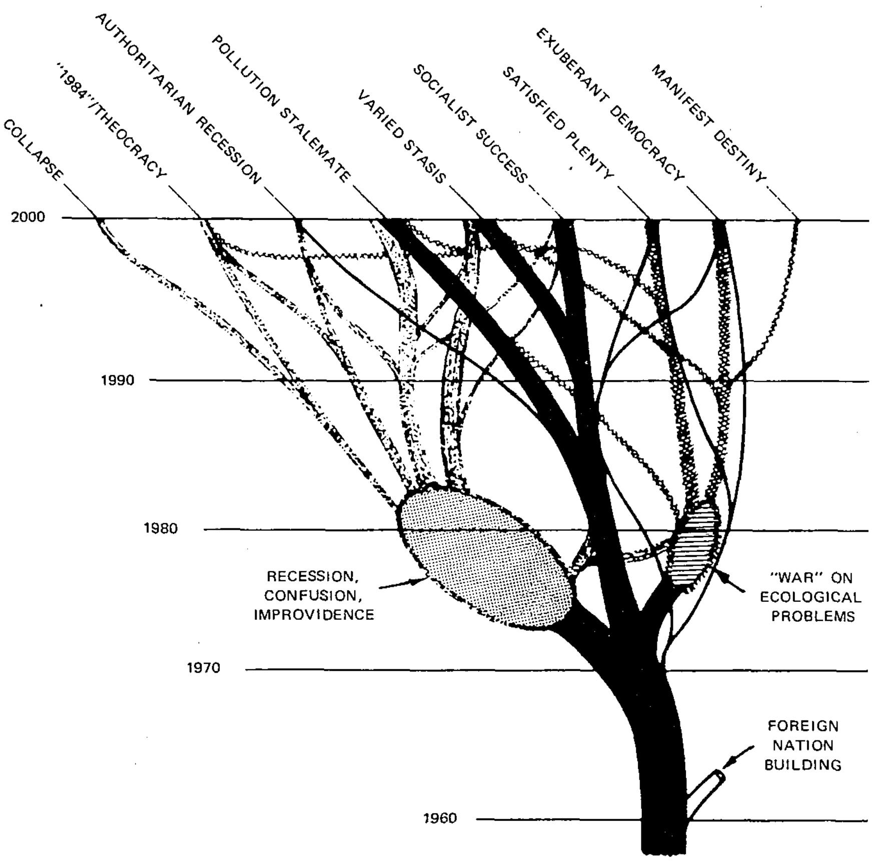

Figure 5. Alternative futures tree. (from Reference 21)

Methodologically, the generation of the alternative futures in the year 2000 began with a morphological analysis which created a broad spectrum of possibilities. After a process of screening (partly by mathematical elimination of any combination containing incompatible factors and partly by intuitive and heuristic judgment of plausibility), only a manageable number of alternative futures remained. A recycling process (allegedly analogous to the relaxation method for solving boundary problems in mathematical physics) resulted in the gestalt description of alternative futures and how they could be logically linked in time sequences as in Fig. 5.

Perhaps the most interesting point and most relevant to environmental issues in Fig. 5 is that an all-out "war" on ecological problems is necessary in the near future if we wish to see the American society proceeding toward the generally more desirable alternatives in the right-hand portion of the spectrum. To wage an all-out war on ecological problems may require a drastic change in our present institutions, goals and values, and social habits. Herein lies the spiritual challenge to America as a nation and, for that matter, to all inhabitants of the spaceship earth.

A Possible Framework for Macrosystem Analysis

What has been discussed up to this point represents only a fraction of the global and long-range approaches to the human environment. There is a rich literature, both in the governments and in the universities, related to the various aspects of the world macroproblem. What is lacking, perhaps, is a systematic integration and expansion of the research results in such a form that they become effective in aiding the public debate and the policy decision process. The purpose of this section is to illustrate a possible framework for the systematic integration and expansion of such policy research.

Since the underlying forces that put unprecedented pressures on the spaceship earth are population and economic growth, the following fundamental questions will help us think about policy research in this area:[22]

1. What would be the effects of alternative patterns of population and economic growth on natural resources, environment, and social systems in a global context?
2. What are the action-oriented policies that would be required to reach the alternative goals of population and economic growth?

To seek specific answers to these questions, one might follow the logical steps in the procedural framework given in Fig. 6. These steps are:

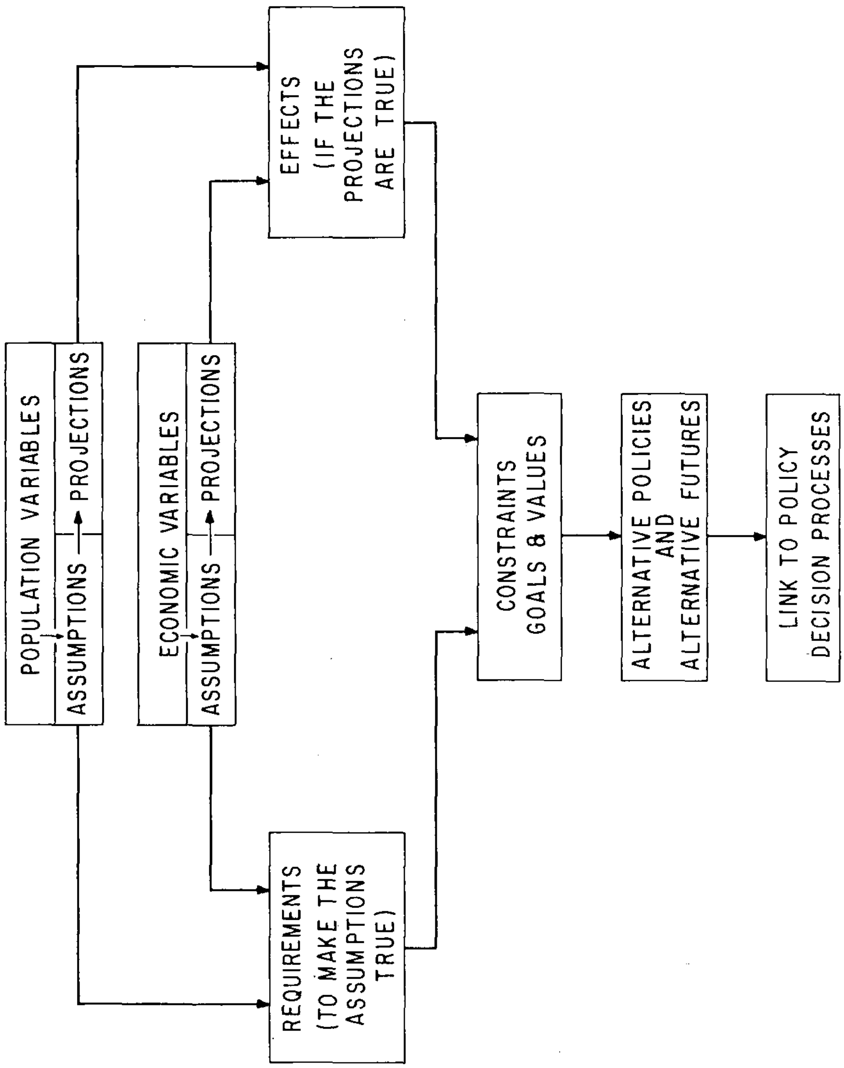

Figure 6. An initial framework for policy research on population and environment.

(1) Select population and economic variables.

Since population growth and economic growth are considered as the primary forces which have exerted pressure on all aspects of the human environment, it would be desirable to select the key variables that describe quantitatively these primary forces of growth. For example, the variables describing population growth patterns would include the rates of birth, death, immigration, and emigration. The variables describing economic growth patterns would include the GNP derived from the production of goods and services. There will be a need for disaggregating goods and services because their productions have different effects on the environment (e.g., different generations of waste products). It will also be important to select as a key economic variable the per capita GNP gap between the well-developed and the less-developed nations because the majority of the inhabitants on earth are striving to narrow this gap. Their success or failure will have a profound impact, one way or another, on the global environment.

(2) Make assumptions of variables.

Since the objective of policy research is to identify alternative policies and relate them to alternative futures, a *range* of assumptions would be made for the selected population and economic variables. The range would include the current growth trends, their reasonable variations, and some drastic changes that have been proposed seriously.

(3) Make projections of variables.

Based on each set of assumptions, projections would be made on population and economic growth patterns. For example, the population growth projections would be made in terms of the age structure, spatial distribution, etc. The economic growth projections would be made in terms of energy consumption, demand for raw materials, etc. Maximum use would be made of existing projections and information. However, existing projections tend to begin with a given set, rather than a range, of assumptions and, therefore, would probably have to be expanded to aid policy choices.

(4) Specify effects.

The effects on the total human environment would be specified for each set of projections of population and economic growth patterns. The effects, to be specified at least in direction if not in magnitude, would include the kinds and amounts of wastes produced, the impact on the conservation of natural resources (land, food, minerals, energy, etc.), and the demand on our service systems (education, housing, transport, communications, etc.).

(5) Specify requirements.

The requirements to make the various assumptions come true would be specified. For example, the requirements for certain population growth patterns to come true could be analyzed in terms of the average number of children wanted and the cost and availability of family planning assistance. The requirements for certain economic growth patterns to come true would include some minimum increase of productivity and of capital cumulation rate.

(6) Analyze constraints, and alternative goals and values.

The problem of relieving the pressure generated by population and economic growth on the human environment is a relative one. The pressure could be reduced either by curtailing growth or by generating resources, the latter including new arrangements for resource conservation and/or technological changes. The overall analysis could be made by mapping environmental constraints, as conceptually illustrated in Fig. 7. Based on the effects specified in Step (4), the successively active environmental constraints (depletion of certain minerals, tolerance limits of certain pollutants, etc.) could be mapped into the space of GNP and population. Similarly, the complete range of alternative growth patterns which our future may reach by a certain year could be mapped in the same diagram. The growth contour comprises the extremal points of the alternative growth patterns. The purpose of the analysis is to find out where and when the growth contour is likely to reach one of the constraints, what would be the consequences if the constraints were reached, what would be the short-term and long-term costs and benefits to set certain goals for preventing certain constraints to be reached, and what values the society must assume in order to reach these goals.

(7) Outline alternative policies and alternative futures.

Based on the alternative goals obtained from Step (6), the alternative policies would be outlined for reaching these goals. The alternative policies could be in the domains of population, economics, science, environment, or some combination of them. These policies would be evaluated in terms of their effectiveness in pushing the environmental constraints out (outward-pointing arrows in Fig. 7) and holding the growth contour back (inward-pointing arrows in Fig. 7). The long-term effect of these policies would also be assessed. For example, the policy of circumventing certain constraints in the near future might lead to more traumatic pressures and perhaps a greater collapse in the more distant future. For each set of alternative policies, the corresponding alternative future would be described in terms of the growth pattern, its environmental effect, and the prevailing social values that must accompany the growth and the corresponding policies.

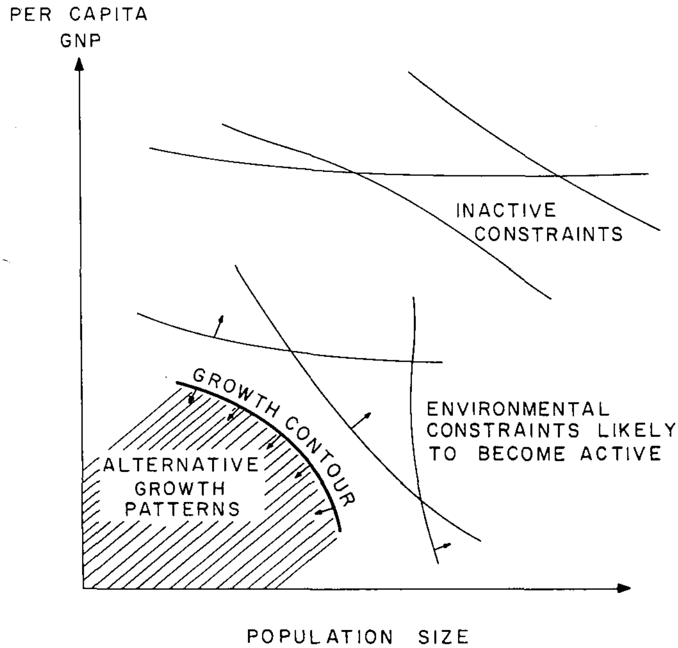

Figure 7. Environmental constraints to economic and population growths.

(8) Link analysis of alternatives to policy-decision processes.

The results of the above steps would be of no avail if they were not used for their intended purposes. The coupling of research results to the policy-decision processes will be critically important, yet unusually difficult, due to the diffuseness of the decision processes in the subject area. Effective ways of linking the policy research to policy decisions would be explored to increase the probability of their use. For example, one way to establish an effective link would be to communicate with policy-makers while the research is being formulated and conducted, instead of disseminating the results after the research is completed.

Conclusions

The world macroproblem has been identified and assessed by human biologists, ecologists, engineers, economists, futurists, and scientists and humanists of many different disciplines. There is a need for integrating their views and proposed solutions in a common framework to facilitate public debate and policy decisions. A possible framework for such macrosystem analysis has been illustrated in this paper. In view of the immense significance and magnitude of the problem, the substantive work on the macrosystem analysis would call for a multinational cooperative effort that can be coupled to the highest level of counsels of national governments and international organizations.

ACKNOWLEDGMENTS

The author is indebted to Robert Lamson for stimulating discussions on the policy research framework suggested in this paper, and to John Brewer, Willis Harman, Dennis Meadows, and Sanford Rose for permission to use their original diagrams.

REFERENCES

1. Arnold J. Toynbee, *Change and Habit*, Oxford University Press, 1966.
2. Kan Chen (ed.), *National Priorities*, San Francisco Press, 1970.
3. "Dean Calls for Group to Study Nation's Goals," *The Stanford Daily*, January 19, 1970.
4. Arthur L. Austin, and John W. Brewer "World Population Growth and Related Technical Problems," *IEEE Spectrum*, December, 1970.
5. Paul R. Ehrlich and Anne H. Ehrlich, *Population, Resources, Environment*, Freeman and Co., 1970.
6. Garrett de Bell (ed.), *The Environmental Handbook*, Ballantine Books, 1970.
7. "Problems of the Human Environment," Report of the Secretary-General, UNESCO Report E/4667, May 26, 1969.
8. Robert Cahn (Member of the President's Council on Environmental Quality), "Engineers and the Environment: A Look into the Future," address at the 8th Annual Meeting of Society of Engineering Science, November, 1970. (Discussion of scope and priority of the environmental problem during the question and answer period.)
9. Allen V. Kneese "Research Goals and Progress Toward Them," Environmental Quality in a Growing Economy, Henry Jarrett (ed.), Johns Hopkins Press, 1966.
10. G. A. Tsongas, E. W. Johnston, C. A. Depew, R. Decher and A. Hertzberg, "A Means of Radiation of Earth Thermal Pollution," *Proc. ENERGY 70*, Fifth Intersociety Energy Conversion Engineering Conference, September, 1970.
11. Ralph Turvey, Side Effects of Resource Use," *Environmental Quality in a Growing Economy, op. cit.*
12. Sanford Rose, "The Economies of Environmental Quality," *Fortune*, (A special issue on The Environment: A National Mission for the Seventies), February, 1970.
13. Wassily Leontief, "Environmental Repercussions and the Economic Structure: An Input-Output Approach," *The Review of Economics and Statistics*, Vol. LII, No. 3, August, 1970.

14. Roger Glasey, "Mathematical Models in the Management of Solid Wastes," An invited address at the 8th Annual Meeting of Soc. of Engineering Science, November, 1970.
15. Arjay Miller, "A Proposal for a National Goals Institute," *National Priorities, op. cit.*
16. Comments by Barry Commoner reported by *Time* (Environment Section), January 11, 1971.
17. Kenneth E. Boulding, "The Economies of the Coming Spaceship Earth," *Environmental Quality in a Growing Economy, op. cit.*
18. Aurelio Peccei, *The Chasm Ahead*, The Macmillan Company, 1969.
19. "The Club of Rome Project on the Predicament of Mankind–Phase One: The Dynamics of Global Equilibrium" (document obtainable from Dennis L. Meadows, Sloan School of Management, M.I.T.), November 6, 1970.
20. Walter Sullivan, "Computers: Probing Questions Too Tough for a Mere Brain," *The New York Times*, Sec. 4, p. 12, December 6, 1970.
21. Willis W. Harman, "Alternative Futures and Educational Policy," Educational Policy Research Center, Stanford Research Inst., January, 1970.
22. Robert W. Lamson, "The Future of Man's Environment," *The Science Teacher*, Vol. 36, No. 1, January, 1969.