AN APPROACH TO THE MODELLING OF GLOBAL ENVIRONMENTAL PROBLEMS

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1. The nature of the problem

Global environmental problems arise in close connection with problems of growing population. Advances in medicine which reflect success in science and technology have a population growth of unprecedented proportions. At present, the doubling time is about 25-30 years; i.e., in 1973 the population of the earth was 3,5 billion; in 2000 it will be about 7 billion. (For some developing countries the doubling time is about 18-20 years, for most of the developing countries about 100 years). Every year the population increases by 80 million. However, the earth is capable of supporting those 7 billion people. There are enough fats, proteins, vitamins and minerals for at least 30 billion people, if all countries adopt the best agricultural technology. 7 billion is very little, if the resources of the oceans will be taken into consideration.

However, these types of estimates are not correct - climate and the oceans in 2000 will be a little bit different from those which we can see in 1974. We are speaking not about natural variations of environmental conditions, but man's impact on the environment. We now have lots of data on how industrial , agricultural, transportational activities of man influence all aspects of the environment (air, water, soil and biota). Even on the open ocean it is very easy to find traces of oil, plastic bottles, etc. and on the glaciers particles of soil which was destroyed by man in the neighboring valley.

The rate of disturbances of material and energy balances on earth as a result of man's activities is so high now that it is possible to talk about an explosion of natural environemtnal conditions. Energy, metal and engineering resourcefulness of man is growing at a rate faster than the population increase.

Total impact of a society on the ecosystem "I" can be expressed by I = P•F where P is the population size, F - impact per capita. Particularly rapid increase in total impact over the past several decades has occurred because both P and F have, in fact, been increasing simultaneously. We can write:

$$I + I = (P + \Delta P)(F + \Delta F)$$

ore $$1 + \frac{\Delta I}{I} = (1 + \frac{\Delta P}{P})(1 + \frac{\Delta F}{F})$$

The population has been doubling for the last 30 years. At the same time, energy production rose 2,5 times per capita.

$$(1 + \frac{\Delta P}{P})(1 + \frac{\Delta F}{F}) = (1 + 1)(1 + 1,5) = 5 = 1 + \frac{\Delta I}{I};$$

and $\frac{\Delta I}{I} = 4$.

It means that total impact of man increased by 400% in a period when population increased only by 100%

During the past hundred years, the population tripled whereas the impact on the environment increased about 50 times. The same figures a hundred years hence bring the population to ~30 times the present number and the impact on the environment to ~10^3 times more than we have now.

Exploitation of the environmental and mineral resources is accelerating at such rapid rates that unforeseen and often unwanted side effects are continually arising.

In this context, some questions will have to be ansered: 1) How long can people move in the same direction without facing serious disasters. 2) What sort of global ecological crisis can arise and how soon will it come. 3) What kind of price people should pay to avoid this crisis. 4) How to keep the earth as good as it is for future generations. 5) What changes can be made on earth and what is extremely important to people and shouldn't be changed. Unfortunately it is not possible to give the answer on a scientific base. It's not realistic to recommend a stop to industrial development or population growth. Specialists in economy, technology, agriculture, demography, social and behavioral sciences, medicine, toxicology, geo-physics, geography and many other sciences are involved now to find solutions to global environmental problems. This problem is so wide and so complicated and encompasses as never before all fields of the sciences. The rapidly increasing magnitude of the problem demands that steps nevertheless be taken to derive at a scientific solution.

Lack of skill or foresight may lead to unwanted environmental side-effects which might be harmful to man and also irreparable or at best extremely costly to undo.

II. The Essence of the Problem

From the very beginning, man started to change the environment. He killed animals for food, he changed communities of grasses on the pasture, he burned down forests, etc. However, the number of people was so small, they had no real impact on the environment.

Astronomical and geophysical processes rule the environment and seriously change it in periods from 10^4 to 10^8 years. For example 10^4 years is a time scale for climatic change and magnetic field change. 10^6 years is a time scale for changing geographical positions, e.g., rivers, seas, and continents; 10^8 years is a time scale for geochemical processes on earth. Now we step into a period where man-made changes are practically equal to natural changes, but from 2000 onward they will be much higher Instead of 10^4-10^8 years, which can be expected from man as a biological object and from the biosphere, man is going to create possibilities for change of environmental conditions with a time scale somewhere between 10^1-10^2 years.

The question is how to continue the development of industry, agriculture and transportation while keeping environmental conditions as they are without spoiling these complex environmental systems upon which all human existence ultimately depends.

Natural processes too produce some pollutants: deserts create clouds of dust, volcanos chemical and thermal pollution, oceans salt pollution etc. Environmental conditions and the biosphere were formed during the earth's history under the influence of natural pollutants. Global environmental conditions are not changed by natural pollutants becuase of the specific balance which exists between sources and sinks of natural pollution.

A quite different situation exists with respect to man-made pollution. Industry and transport produce numerous poisonous substances with which organisms have had no prior evolutionary experience. The high rate of consumption of organic and raw materials creates unusual types of pollution for which sinks are unknown in nature. Until recently, there was little interest in sinks of pollutions. As a result some fertilizers, herbicides, pesticides and metals find their sinks in the biosphere, in animals, in people or in the soil, thereby reducing its fertility.

The waste products of aluminum, cryolite and superphosphate branches of industry fall out on the soil and create artifical geochemical zones with excess transition of fluorine to plants and animals ecologically linked with human population. Studies of populations living close to aluminum steel or cement plants identified fluorosis of varying severity among both children and adults. In agricultural areas, the population receives some of the pesticides from the air during their work in the fields (10%), but most at home from food and water (90%). Through food and water, pesticide reaches people living in other countries and other continents.

One of the most common industrial poisons is certainly the carbon oxide (CO) which at the same time turns out to be a widespread poison of everyday life. Products of incomplete combustion of natural and artifical gases as well as other kinds of fuel burned in apartments , exhaust gases emitted by automobiles, and waste products of communal enterprises together with metal pollutants, are the main sources of air pollution. The people in oil-producing regions are constantly exposed to carbon pollutants.

Experimental studies demonstrate in particular that a simultaneous reception of chemical compounds coming through the alimentary canal and the respiratory system on the threshold level has a cumulative effect.

Different levels of concentration produce different effects according to the properties of the poison. In particular, the following properties are very important: solubility of the substance in water, the speed of blood saturation, speed of transformation in the organism, the ways and speed of excretion and the cumulative capacity of the substance.

It should be stressed that the problem of complex exposure to chemical compounds has not yet been solved.

The biosphere and the climate are without doubt more sensitive to man-made pollutions. Changes in circulation and balance of such chemical elements as C,N,S, have immediate influence on the biosphere and indirect influence on the CO_2, N_1O, NO_2 and O_3 molecules in the atmosphere and/consequently on the climate. Man, changes the radiation balance of the atmosphere not onlv by altering its CO_2,N_1O, NO_2,O_3 composition and particulate content, but also by changing the reflectivity of the surface of the earth through irrigation, urbanization, turbidity of the air, etc. Productivity of agriculture in its turn is very sensitive both to the wellbeing of the biosphere (including fertility of the soil) and to climatic conditions (light, temperature and water).

Industrial capacity depends partly on the health of people, agricultural products, and environmental conditions. When changing air, water, and soil,one can expect some repercussions in the biosphere, climate, productivity of agriculture, and even in industry and transport. Now we are able to recognize how serious the consequences might be, but we still are not able to calculate them exactly.

III. Environmental and Mineral Resources and Pollution

The main elements of the environment are water, air and soil, through which natural and man-made pollution is distributed into all part of the biosphere including man. Water, air, soil and energy of the sun together create and support the biosphere which is a very delicate system. The limited space where the biosphere can exist looks like a thin film on the earth. Unfortunately, the same space is used for agriculture, industry and transport systems serving man. The question is how to optimize this system, how to combine the high level activities of man with high quality environmental conditions.

Trying to satisfy his needs, man uses mineral and energy resources (oil, coal, ore, etc.) together with environmental resources (air, water, soil, resources of the biosphere) and disperses the former into the latter. Sometimes all traces of man's activity are called "pollution" -- pollution in the broadest sense of the word. Shore erosion, degradation of natural ecosystems with the loss of gene pools, radioactivity, etc., if a result of man's acitivities, can be called "pollution". All types of pollution affect man economically, aesthetically, and in his health.

In many cases to protect the environment from pollution is an unsolvable task if we want to have cheap products. In many cases it is possible to partly reduce pollution, but this action costs as much as the product itself. For example, desulphurization of coal and oil is very expensive.

The price of cleaning up soil, air or water or of protecting them from pollution goes up with the proportion of pollution being tackled. (see Fig.1).

Pollution is a satellite of man's activity in any field. Some of the pollutants can be utilized as a raw material for the production of new things, but most of them cannot be collected, such as dust of fertilizers, mineral ore and soil, the heat of engines, erosions, etc.

To prevent one kind of pollution and change it into another which is not toxic or which is easier to recycle, new and more effective technology must be developed.

Now we come to an area where the unknown is very high. New results in science are very difficult to forecast but it would be even more difficult to try and forecast if these results will be converted into new techonology or not. It would, furthermore, be difficult if somebody tried to predict the time when such new technology came into operation. Practical effectiveness of new technology as well as the composition of pollutants from it can be appreciated only after a new factory or plant starts normal operations.

The same kind of difficulties arise when anybody tries to appreciate what principal new mineral and energy resources will be available in the future when they become usable. These problems are again connected with the development of science. Quantity and quality of mineral resources can be estimated only from the point of view of today's technology. New and more effective, "cleaner" technology which will come in the future and prevent pollution disasters can very likely make use of new mineral resources and new sources of energy. Pollution is a strong limiting factor for the development of industry, agriculture and transportation systems, now spoiling all environmental resources and resources of the biosphere including man. (Some scientists believe that one of the reasons of acceleration in people's body growth is the increase in radioactivity after the atomic bomb explosions).

Let us look at Fig.2 which helps us to understand the situation. On the left side, resources of the world are shown. Air, water and soil - the main environmental resources are reflected in the climatic conditions and intimately connected with resources of the biosphere. Inside the limited space occupied by the biosphere the world's population grows. As long as the population grows, the demand for more products rises and stimulates industrial, agricultural and other activities. Scientific developments, which depend partly on the size of a growing population, help to find mineral and energy resources and a suitable technology to support the development of industry, agriculture and transport systems.

Thick arrows used in Fig.1 reflect relationships which cannot now be mathematically expressed nor predicted. The relations of (population) ⟶ (demand for products) ⟶ (industrial activity) have been investigated by sociologist and behavioral scientists, but no functions have been suggested.

Relationships which can be appreciated and calculated more easily are shown in Fig. 2 by thin arrows. If all kinds of pollution were expressed in units of damage to the world environment (including aesthetic and moral wealth); it would be possible to create a model for calculating losses which must be borne in the future to allow further development of industry, agriculture and transportation systems. In the case of too high prices for development, the model can show what kind of technology should be changed and what are the needs for new technology. If the rate of development of industry is known, it will be possible to find data which can be used for new technological processes with the aid of the model. A model of such a type is very important for solutions of global environmental problems and for the creation of scientific cases to answer the questions which were mentioned above. Such a model would serve as an alarm model which recognizes when and what kind of crises in environmental conditions might be expected.

On the other hand, the environment is a very important link between all branches of man's activity. All of man's activities and his way of life are reflected in the environment. We can show it in a very simple scheme in Fig. 3. This important property of environment urges us to use indices of quality of environment in global modelling rather than money, material, energy, indices. Practically, we cannot express the wellbeing of present and future generations in terms of money or energy as well as cultural, aesthetic and moral values. At the same time, indices of environmental quality can be easily converted to units of money or energy because we know the price of reconstructing natural environmental conditions or for preventing pollution.

In global models money, enery or material goods usually circulate and provide the link between submodels. It is good from a thermodynamical or economical point of view to consider industry, transport or energy development. Environmental indices of quality (explanation follows) are much pre erable for extensive global modelling because industrial, agricultural, transportational activities as well as population, urbanization, and some other processes on earth can be easily described with them.

Connections between different parts of the model are usually difficult to create. Some scientists believe that the lack of existing global models is due to shortage of mutual relations between submodels reflecting different spheres of man's activity. This can possibly be overcome with the introduction of quality environmental indices as a circulating value together with monetory and energy values.

IV Status of the Problem

Our knowledge of the flow of materials through the economic system and their loss or dispersal to the environment is extremely limited, especially with respect to industry. We can calculate how many pollutants we produce now by making one ton of oil, steel or cotton, one ship or car or one pair of shoes. We can calculate "input" pollution in a system but we have little information concerning the pollution "output" from the system. The need for the solution of these problems forces people to organize national and international organizations, commissions and programs on environmental questions.

The following international organizations are now working on global environmental problems:

United Nations Environmental Programme (UNEP) - carrying out its function of reviewing and coordinating the existing and planned environmental activities.

Scientific Committee on Problems of the Environment (SCOPE) - providing scientific bases for environmental activities.

Scope Centre for Environmental monitoring and assessment (SCEMA)

UNESCO - is involved in "Man and the Biosphere"

The World Meteorological Organization(WMO) - is organizing programs on man-made weather modifications and climatic changes.

The World Health Organization (WHO) - is concerned with the development of environmental health criteria and standards as well as the development of food standards together with (FAO)

Special commissions on environmental problems are working in most of the developed countries.

Environmental problems concern not only developed but also developing countries because they are closely connected with the problems of growing population and food production.

Global environmental problems cannot be considered as ordinary natural science problems because they not only describe natural phenomena but also include man's decision-making. This is a multidisciplinary problem which should be investigated in institutes where specialists of different fields of the science are working. The problem is international as far as it is concerned with climate, oceans, fertility of soil, etc. and it should be developed in international institutes. Maybe the most important thing is the fact that these problems are extremely complicated and probably cannot be solved without systems analysis.

These problems remind one of the problem of radioactive pollution yet they are completely different. In the case of radioactive pollution there was the constant hope that it will decrease if nuclear tests are stopped. On the other hand, nobody can have such hopes for the decrease of all kinds of industrial pollution in future. The difficulties of new environmental problems are connected with numerous factors which influence environmental conditions. A small reduction of soil fertility, a small decrease in precipitation and temperature, and a degradation of some plants as a result of a gene code degradation will cause severe food shortages on a world-wide scale. As a result of steadily increasing pollution of various kinds, we are faced with unexpected phenomena, which are especially dangerous.

Most of the global models take production and consumption as the main goal for their predictions. In these models the main limiting factor for development is mineral resources. Taking into consideration the history of man's development and bearing in mind the progress made in geophysics and geology, there are reasons to believe that neither mineral nor energy problem will in future be so acute as the environmental problems of preservation of environmental resources (air, soil, water and resources of the biosphere). We can believe that future progress in sciences can change our position with respect to resources or sources of energy, but it would not change the dimensions of earth's space where man has to live and man's industrial, agricultural and transportational activities are going on.

The situation can be easily understood by comparing the data of the expected world crises from the point of view of current technology.

Shortage of coal - after 400 years
Shortage of gas and oil - after 100 years
Shortage of iron ore - after 600 years
Shortage of precious metals - after 80 years

Quite different figures apply to global environmental problems.

Shortage of fresh water	- after 30 years
Shortage of fresh air	- after 50 years
Shortage of timber	- after 20 years
Shortage of ocean fish	- after 10 years
Shortage of food	- at present

There have always been crises concerning available technology. When one type of animal was exterminated through hunting by prehistoric man, he changed his technology and used another type of animal as food. One technological crisis made man a shepherd, another one pushed him to plough the soil. Now man faces a food crisis and should change his technology; instead of the ancient practice of utilizing the soil it should be accepted practice in developing countries to use fertilizers, but this creates a worse situation with respect to environmental problems.

We may expect another two crises in the future: a crisis connected with burning oil, coal and gas in engines and in factories and a crisis connected with the abundance of available energy. Both can cause climatic change and poisoning and degradation of the biosphere. We are again faced with environmental problems which need: a) proper scientific description; b) a universal solution based on a new approach in technology.

V Monitoring and Environmental Indicators

Some plants and living creatures are able to collect organic molecules and metals from the environment. This useful function, however, can cause their death under abnormal environmental conditions. That is why the idea arose to consider some biospheric values as the best indices reflecting environmental conditions. The biological health and ecological balance should reflect not only chemical pollution effects, but all kinds of man's tampering with the biosphere, including the effects of selection and poor management, which can be considered as a specific kind of pollution. Long-term effects of man's activities may destroy the biogeochemical cycles vital to all life.

It was suggested to use biological indicators as indices of quality of the environment, such as the thickness of egg shells, the composition of blood, length and weight of some organs, the distribution of age groups, statistics of illnesses, and so on. The sensitivity of biological indicators is very high because organisms are able to integrate different chemical influences, which is not possible for physical devices. Organisms sometimes are able to reflect small changes in environmental conditions which are beyond the sesitivity of physical devices. The probability to be faced with unexpected things dangerous to man will be quite low if observations of individuals, communities and ecosystems will be arranged.

However, it is not clear up to now what kind of creatures should be selected and chosen for biological monitoring. There is a great need for pilot studies and basic research of the structure and function of the biosphere before a detailed biological monotoring program can be designed.

Environmental indices and indicators are useful means of observing trends, analyzing programs and informing people of important concepts in a simple, understandable manner. In contrast to the highly developed economical or meteorological indices, environmental indices are just now being defined.

The second part of monitoring is designed to collect geo-chemical, biochemical, and toxicological indices. It is considered desirable to know the flows and balances of energy, CO(CO_2), nitrogen, phosphorous, DDT and maybe some other elements important for life (SO_2,U_2 , O_3,F, Cl, Cd, Be, Cr, PV, Zu, Cu, Ni, Un, Se). It is proposed to find out sources and sinks for these components and some organic molecules.

The third part of monitoring consists of routine meteorological, hydrological and geophysical observations, which have a good history and can be easily interpreted in a physical way.

To these three types of environmental indices (biological, chemical and geophysical) can be added social-aesthetic indices In contrast to natural phenomena, social-aesthetic conditions are entirely the results of human actions and reflect the state of the man-made environment. Recreational and cultural facilities and residential conditions are usually included in some sort of social index; and noise, odors, and visual insults such as "urban blight" can be included into aesthetic indices. Practically, we can recognize a fourth part of monitoring, observations of the environment from a social-aesthetic point of view, and create specific indices. Common learn about the changes in the environment by such indices as they personally created.

Difficulties arise when attempts are made to combine all types of indices to create a few essential ones instead of hundreds. It is believed that skillful scientific analysis combined with systems analysis provides some recommendations for the construction of a few important, as well as universal, indices. A preliminary analysis should be based upon the following factors: impact, utility, value, cost and importance. It should always be taken into account that pollutions are divided in two categories: local (regional) and global, which can be observed as a background pollution. Both influence environmental and biological resources on a global scale. A quality index of the environment (Q) can be given as

$$Q = 1 - P$$

where P is an index of pollution.

$$P = \frac{1}{M} \sum_{i=1}^{n} b_i \frac{M_i}{S_i} ;$$

where

S_i = standard concentration for pollutant i

M_i = measured values at fixed time and at a fixed place;

b_i = relative weights assigned to each percentile of pollutant i,

M = factor that ensures that P does not exceed unity.

i = 1,2,..., n - pollutants

The quality environmental index Q can be used at any time in spite of changing pollutants. If we know the values of "b_i" for SO_2, CO, NO_2, dust, heavy metals, soil erosion, landscape damage, and so on, we can calculate environmental degradation for periods of 1, 5 or 100 years. Utilizing the quality environmental index Q we can make comparisons between two areas exposed to different pollutants in spite of the fact that one area is very bad with respect to, for example, CO in the air, but another one with respect to water quality and landscape degradation. The only problem is to find the values of "b_i". This problem is intimately connected with monitoring. Pollutants, which have a high value of "b_i", should be included in any monitoring system. Pollutants with a b_i value about zero can be left out. To find the proper value of "b_i", special socio-medical investigations are under way in different countries.

Proper monitoring should check the pollutants chosen from the point of view of their spreading. After that, a corresponding network of monitoring stations should be set up. Normally, any network of stations (for meteorological or geophysical data) is established by trial and error. It is not easy to create such a network for some element of the environment about which not much is known. In the case of global environmental problems the unknown is much greater--we are still looking for better indicators. However, time is limited and at present, some indicators and networks of monitoring are coming into operation.

VI Conclusions

1. Global environmental problems, GEP, are extremely important scientific problems, connected with the well-being of man.

2. GEP are complicated, multidisciplinary problems connected with the exhaustion of limited environmental resources and resources of the biosphere and partly connected with the mineral resources on earth.

3. GEP are international problems connected with such international concerns as the limited dimension of the earth, limited air, soil, and water resources and shortages of food.

4. There is a great need for the creation of scientific bases from which it will be possible to get answers to numerous questions connected with GEP.

5. Environmental and biospheric resources are a real value for living and future generations utilization of which

should be based on complete knowledge.

6. The successful development of economic indices in the last decades allowed us to construct some global and regional models of industrial development, in which the main focus was put on the economic question and on the exhaustion of mineral resources. Not much has been done with existing models concerning appreciation of environmental and biological resources. The difficulties with indicators of quality such as the complexity of the problem and the abundance of important factors prevent scientists from building global models to seek the solution of GEP.

7. The exhaustion of global environmental and bioshperic resources is one of the critical problems on earth. Local and regional environmental problems connected with the emission of pollutants from certain sources are practically solved now.

This short survey of global environmental problems cannot encompass all the important interconnected areas We did not touch, for example, on existing practices to dispose waste on the bottom of the oceans or in deep mines, on preservation of continental ice, on governments' activities to prevent pollution, and so on. The task of this report is to draw attention to critical needs for the creation of a global environmental model in which many other global problems (food, industrial development, mineral resources, energy use, urbanization, etc.) can be included. We can express our private opinion that IIASA would be able to start a special decade of investigation and evaluation of .obal environmental modelling using multidisciplinary systems analysis oriented staff.

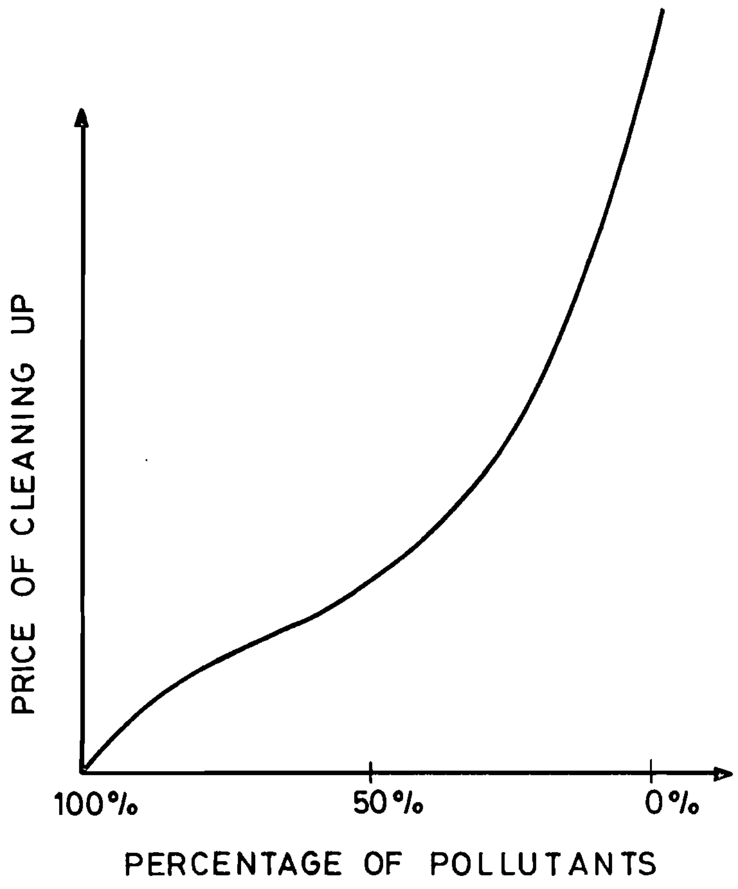

FIGURE 1

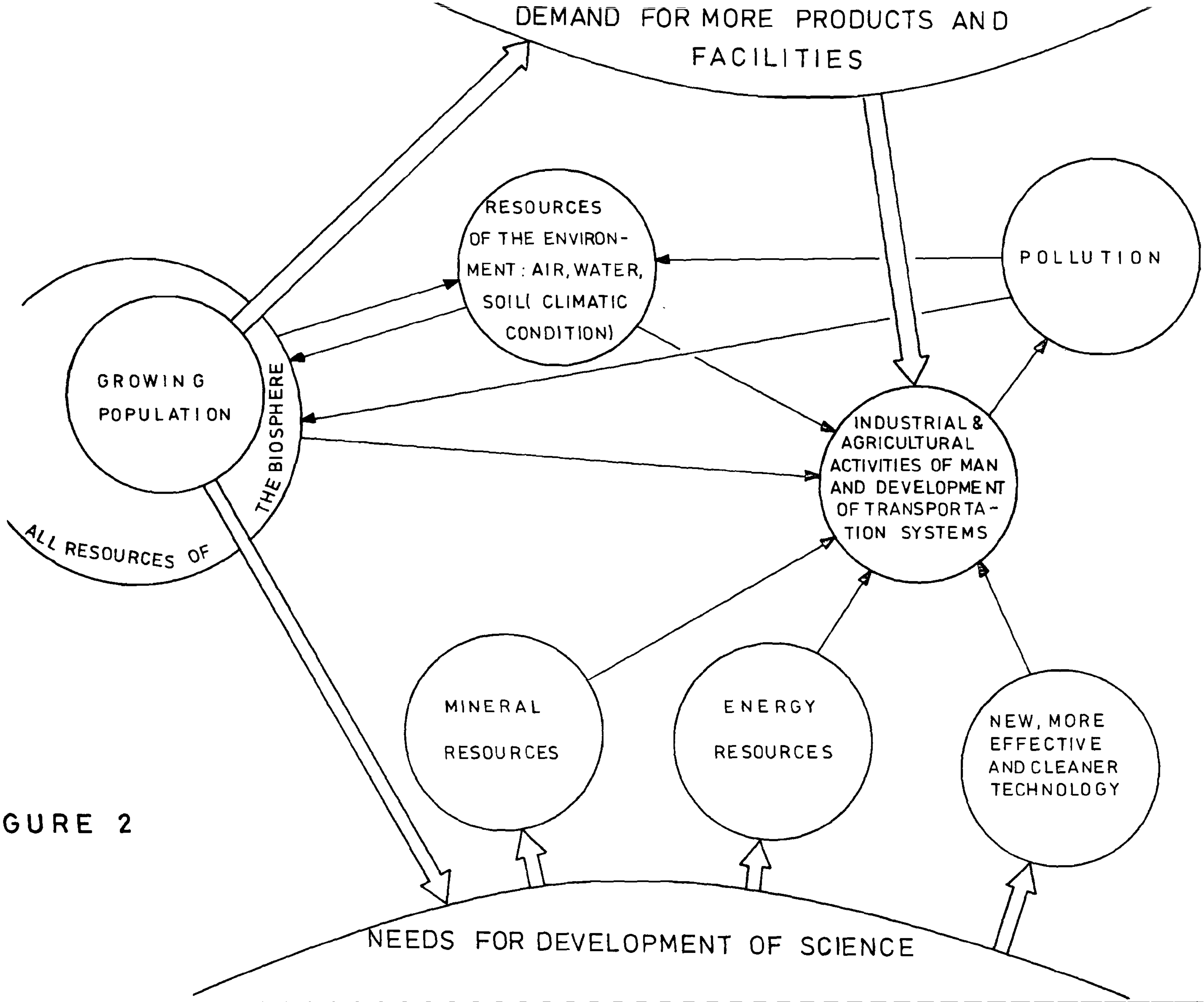
DEMAND FOR MORE PRODUCTS AND FACILITIES
RESOURCES OF THE ENVIRONMENT: AIR, WATER, SOIL(CLIMATIC CONDITION)
POLLUTION
GROWING POPULATION
THE BIOSPHERE
ALL RESOURCES OF
INDUSTRIAL & AGRICULTURAL ACTIVITIES OF MAN AND DEVELOPMENT OF TRANSPORTATION SYSTEMS
MINERAL RESOURCES
ENERGY RESOURCES
NEW, MORE EFFECTIVE AND CLEANER TECHNOLOGY
NEEDS FOR DEVELOPMENT OF SCIENCE

FIGURE 2

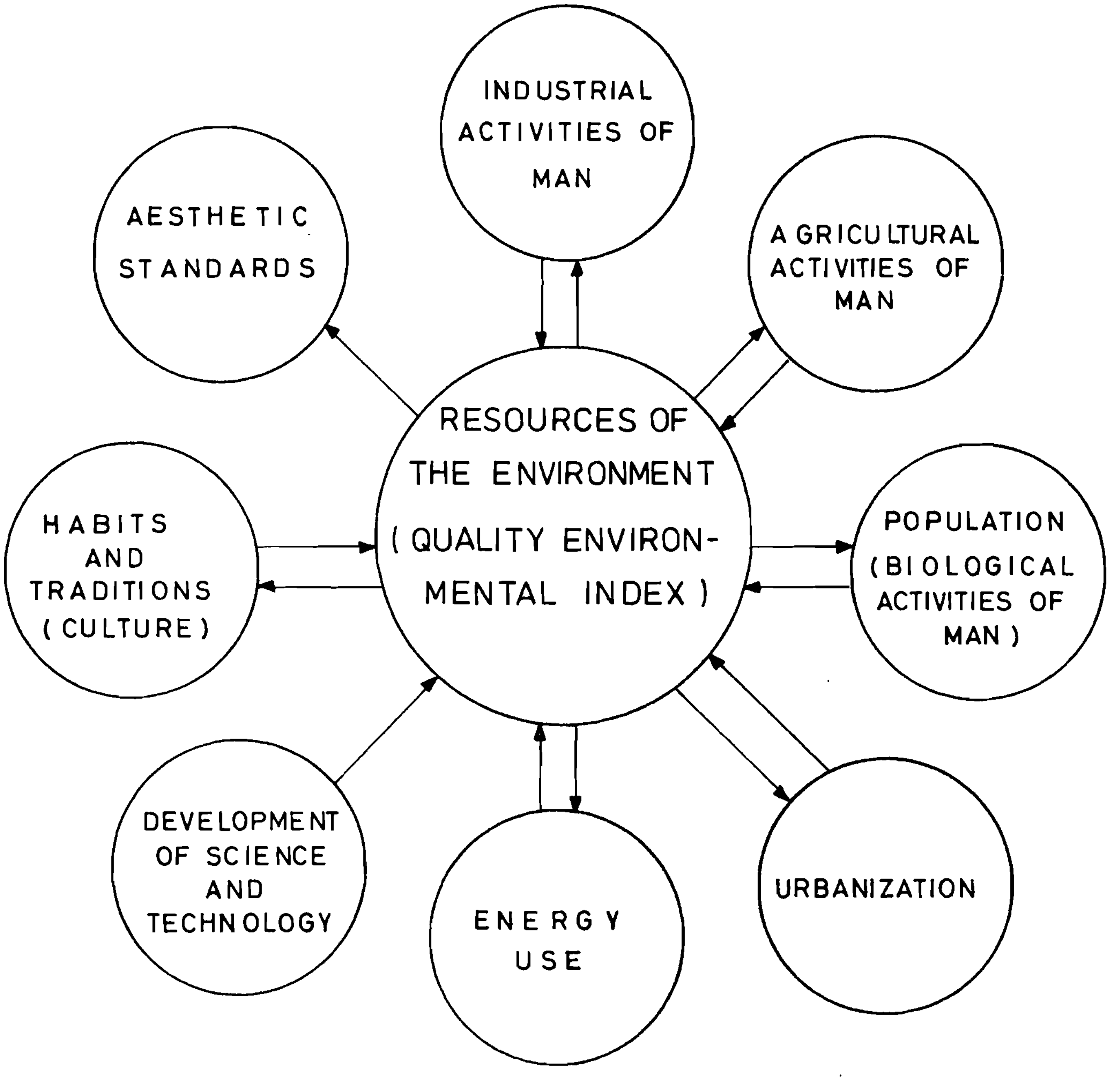
INDUSTRIAL ACTIVITIES OF MAN
AESTHETIC STANDARDS
AGRICULTURAL ACTIVITIES OF MAN
RESOURCES OF THE ENVIRONMENT (QUALITY ENVIRONMENTAL INDEX)
HABITS AND TRADITIONS (CULTURE)
POPULATION (BIOLOGICAL ACTIVITIES OF MAN)
DEVELOPMENT OF SCIENCE AND TECHNOLOGY
ENERGY USE
URBANIZATION

FIGURE 3