The Limits to Growth

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by Donella H. Meadows, Dennis l. Meadows, Jorgen Randers, William W. Behrens III

Short Version of the Limits to Growth

Our world model was built specifically to investigate five major trends of global concern – accelerating industrialization, rapid population growth, widespread malnutrition, depletion of nonrenewable resources, and a deteriorating environment.

The model we have constructed is, like every model, imperfect, oversimplified, and unfinished.

In spite of the preliminary state of our work, we believe it is important to publish the model and our findings now. (...) We feel that the model described here is already sufficiently developed to be of some use to decision-makers. Furthermore, the basic behavior modes we have already observed in this model appear to be so fundamental and general that we do not expect our broad conclusions to be substantially altered by further revisions.

Our conclusions are:

1. If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.

2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his individual human potential.

If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.

All five elements basic to the study reported here--population, food production, and consumption of nonrenewable natural resources--are increasing. The amount of their increase each year follows a pattern that mathematicians call exponential growth.

A quantity exhibits exponential growth when it increases by a constant percentage of the whole in a constant time period.

Such exponential growth is a common process in biological, financial, and many other systems of the world.

Exponential growth is a dynamic phenomenon, which means that it involves elements that change over time.

(...) When many different quantities are growing simultaneously in a system, however, and when all the quantities are interrelated in a complicated way, analysis of the causes of growth and of the future behavior of the system becomes very difficult indeed.

Over the course of the last 30 years there has evolved at the Massachusetts Institute of Technology a new method for understanding the dynamic behavior of complex systems. The method is called System Dynamics. The basis of the method is the recognition that the structure of any system--the many circular, interlocking, sometimes time-delayed relationships among its components--is often just as important in determining its behavior as the individual components themselves. The world model described in this book is a System Dynamics model.

Extrapolation of present trends is a time-honored way of looking into the future, especially the very near future, and especially if the quantity being considered is not much influenced by other trends that are occurring elsewhere in the system. Of course, none of the five factors we are examining here is independent. Each interacts constantly with all the others. We have already mentioned some of these interactions.

Population cannot grow without food, food production is increased by growth of capital, more capital requires more resources, discarded resources become pollution, pollution interferes with the growth of both population and food.

Furthermore, over long time periods each of these factors also feeds back to influence itself.

In this first simple world model, we are interested only in the broad behavior modes of the population-capital system. By behavior modes we mean the tendencies of the variables in the system (population or pollution, for example) to change as time progresses.

A major purpose in constructing the world model has been to determine which, if any, of these behavior modes will be most characteristic of the world system as it reaches the limits to growth. This process of determining behavior modes is "prediction" only in the most limited sense of the word.

Because we are interested at this point only in broad behavior modes, this first world model needs not be extremely detailed. We thus consider only one general population, a population that statistically reflects the average characteristics of the global population. We include only one class of pollutants--the long-lived, globally distributed family of pollutants, such as lead, mercury, asbestos, and stable pesticides and radioisotopes--whose dynamic behavior in the ecosystem we are beginning to understand. We plot one generalized resource that represents the combined reserves of all nonrenewable resources, although we know that each separate resource will follow the general dynamic pattern at its own specific level and rate.

This high level of aggregation is necessary at this point to keep the model understandable. At the same time it limits the information we can expect to gain from the model.

Can anything be learned from such a highly aggregated model? Can its output be considered meaningful? In terms of exact predictions, the output is not meaningful.

On the other hand it is vitally important to gain some understanding of the causes of growth in human society, the limits to growth, and the behavior of our socio-economic systems when the limits are reached.

All levels in the model (population, capital, pollution, etc.) begin with 1900 values. From 1900 to 1970 the variables agree generally with their historical value to the extent that we know them. Population rises from 1.6 billion in 1900 to 3.5 billion in 1970. Although the birth rate declines gradually, the death rate falls more quickly, especially after 1940, and the rate of population growth increases. Industrial output, food and services per capita increase exponentially. The resource base in 1970 is still about 95 percent of its 1900 value, but it declines dramatically thereafter, as population and industrial output continue to grow.

The behavior mode of the system is that of overshoot and collapse. In this run the collapse occurs because of nonrenewable resource depletion. The industrial capital stock grows to a level that requires an enormous input of resources. In the very process of that growth it depletes a large fraction of the resource reserves available. As resource prices rise and mines are depleted, more and more capital must be used for obtaining resources, leaving less to be invested for future growth. Finally investment cannot keep up with depreciation, and the industrial base collapses, taking with it the service and agricultural systems, which have become dependent on industrial inputs (such as fertilizers, pesticides, hospital laboratories, computers, and especially energy for mechanization). For a short time the situation is especially serious because population, with the delays inherent in the age structure and the process of social adjustment, keeps rising.

Population finally decreases when the death rate is driven upward by lack of food and health services. The exact timing of these events is not meaningful, given the great aggregation and many uncertainties in the model. It is significant, however, that growth is stopped well before the year 2100. We have tried in every doubtful case to make the most optimistic estimate of unknown quantities, and we have also ignored discontinuous events such as wars or epidemics, which might act to bring an end to growth even sooner than our model would indicate. In other words, the model is biased to allow growth to continue longer than it probably can continue in the real world. We can thus say with some confidence that, under the assumption of no major change in the present system, population and industrial growth will certainly stop within the next century, at the latest.

To test the model assumption about available resources, we doubled the resource reserves in 1900, keeping all other assumptions identical to those in the standard run. Now industrialization can reach a higher level since resources are not so quickly depleted. The larger industrial plant releases pollution at such a rate, however, that the environmental pollution absorption mechanisms become saturated. Pollution rises very rapidly, causing an immediate increase in the death rate and a decline in food production. At the end of the run resources are severely depleted in spite of the doubled amount initially available.

Is the future of the world system bound to be growth and then collapse into a dismal, depleted existence? Only if we make the initial assumption that our present way of doing things will not change. We have ample evidence of mankind's ingenuity and social flexibility. There are, of course, many likely changes in the system, some of which are already taking place. The Green Revolution is raising agricultural yields in non industrialized countries. Knowledge about modern methods of birth control is spreading rapidly.

Although the history of human effort contains numerous incidents of mankind's failure to live within physical limits, it is success in overcoming limits that forms the cultural tradition of many dominant people in today's world. Over the past three hundred years, mankind has compiled an impressive record of pushing back the apparent limits to population and economic growth by a series of spectacular technological advances. Since the recent history of a large part of human society has been so continuously successful, it is quite natural that many people expect technological breakthrough to go on raising physical ceilings indefinitely.

Will new technologies alter the tendency of the world system to grow and collapse?

Let us assume, however, that the technological optimists are correct and that nuclear energy will solve the resource problems of the world.

Let us also assume a reduction in pollution generation all sources by a factor of four, starting in 1975.

Let us also assume that the normal yield per hectare of all the world's land can be further increased by a factor of two. Besides we assume perfect birth control, practiced voluntarily, starting in 1975.

All this means we are utilizing a technological policy in every sector of the world model to circumvent in some way the various limits to growth. The model system is producing nuclear power, recycling resources, and mining the most remote reserves; withholding as many pollutants as possible; pushing yields from the land to undreamed-of heights; and producing only children who are actively wanted by their parents. The result is still an end to growth before the year 2100.

Because of three simultaneous crises. Overuse of land leads to erosion, and food production drops. Resources are severely depleted by a prosperous world population (but not as prosperous as the present US population). Pollution rises, drops, and then rises again dramatically, causing a further decrease in food production and a sudden rise in the death rate. The application of technological solutions alone has prolonged the period of population and industrial growth, but it has not removed the ultimate limits to that growth.

Given the many approximations and limitations of the world model, there is no point in dwelling glumly on the series of catastrophes it tends to generate. We shall emphasize just one more time that none of these computer outputs is a prediction. We would not expect the real world to behave like the world model in any of the graphs we have shown, especially in the collapse modes. The model contains dynamic statements about only the physical aspects of man's activities. It assumes that social variables--income distribution, attitudes about family size, choices among goods, services, and food--will continue to follow the same patterns they have followed throughout the world in recent history. These patterns, and the human value they represent, were all established in the growth phase of our civilization. They would certainly be greatly revised as population and income began to decrease. Since we find it difficult to imagine what new forms of human societal behavior might emerge and how quickly they would emerge under collapse conditions, we have not attempted to model such social changes. What validity our model has holds up only to the point in each output graph at which growth comes to an end and collapse begins.

The unspoken assumption behind all of the model runs we have presented in this chapter is that population and capital growth should be allowed to continue until they reach some "natural" limit. This assumption also appears to be a basic part of the human value system currently operational in the real world. Given that first assumption, that population and capital growth should not be deliberately limited but should be left to "seek their own levels", we have not been able to find a set of policies that avoids the collapse mode of behavior.

The hopes of the technological optimists center on the ability of technology to remove or extend the limits to growth of population and capital. We have shown that in the world model the application of technology to apparent problems of resource depletion or pollution or food shortage has no impact on the essential problem, which is exponential growth in a finite and complex system. Our attempts to use even the most optimistic estimates of the benefits of technology in the model did not prevent the ultimate decline of population and industry, and in fact did not in any case postpone the collapse beyond the year 2100.

Unfortunately the model does not indicate, at this stage, the social side-effects of new technologies. These effects are often the most important in terms of the influence of a technology on people's lives.

Social side-effects must be anticipated and forestalled before the large-scale introduction of a new technology.

While technology can change rapidly, political and social, institutions generally change very slowly. Furthermore, they almost never change in anticipation of social need, but only in response to one.

We must also keep in mind the presence of social delays--the delays necessary to allow society to absorb or to prepare for a change. Most delays, physical or social reduce the stability of the world system and increase the likelihood of the overshoot mode. The social delays, like the physical ones, are becoming increasingly more critical because the processes of exponential growth are creating additional pressures at a faster and faster rate. Although the rate of technological change has so far managed to keep up with this accelerated pace, mankind has made virtually no new discoveries to increase the rate of social, political, ethical, and cultural change.

Even if society's technological progress fulfills all expectations, it may very well be a problem with no technical solution, or the interaction of several such problems, that finally brings an end to population and capital growth.

Applying technology to the natural pressures that the environment exerts against any growth process has been so successful in the past that a whole culture has evolved around the principle of fighting against limits rather than learning to live with them.

Is it better to try to live within that limit by accepting a self-imposed restriction on growth? Or is it preferable to go on growing until some other natural limit arises, in the hope that at that time another technological leap will allow growth to continue still longer? For the last several hundred years human society has followed the second course so consistently and successfully that the first choice has been all but forgotten.

There may be much disagreement with the statement that population and capital growth must stop soon. But virtually no one will argue that material growth on this planet can go on forever. At this point in man's history, the choice posed above is still available in almost every sphere of human activity. Man can still choose his limits and stops when he pleases by weakening some of the strong pressures that cause capital and population growth, or by instituting counterpressures, or both. Such counterpresures will probably not be entirely pleasant. They will certainly involve profound changes in the social and economic structures that have been deeply impressed into human culture by centuries of growth. The alternative is to wait until the price of technology becomes more than society can pay, or until the side-effects of technology suppress growth themselves, or until problems arise that have no technical solutions. At any of those points the choice of limits will be gone.

Faith in technology as the ultimate solution to all problems can thus divert our attention from the most fundamental problem--the problem of growth in a finite system--and prevent us from taking effective action to solve it.

On the other hand, our intent is certainly not to brand technology as evil or futile or unnecessary. We strongly believe that many of the technological developments mentioned here--recycling, pollution-control devices, contraceptives--will be absolutely vital to the future of human society if they are combined with deliberate checks on growth. We would deplore an unreasoned rejection of the benefit of technology as strongly as we argue here against an unreasoned acceptance of them. Perhaps the best summary of our position is the motto of the Sierra Club: "Not blind opposition to progress, but opposition to blind progress".

We would hope that society will receive each technological advance by establishing the answers to three questions before the technology is widely adopted. The questions are:

- What will be the side-effects, both physical and social, if this development is introduced on a large scale?

- What social changes will be necessary before this development can be implemented properly, and how long will it take to achieve them?

- If the development is fully successful and removes some natural limits to growth, what limit will the growing system meet next? Will society prefer its pressures to the ones this development is designed to remove?

We are searching for a model that represents a world system that is:

1. sustainable without sudden and uncontrollable collapse; and

2. capable of satisfying the basic material requirements of all of its people

The overwhelming growth in world population caused by the positive birth-rate loop is a recent phenomenon, a result of mankind's very successful reduction of worldwide mortality. The controlling negative feedback loop has been weakened, allowing the positive loop to operate virtually without constraint.

There are only two ways to restore the resulting imbalance. Either the birth rate must be brought down to equal the new, lower death rate, or the death rate must rise again. All of the "natural" constraints to population growth operate in the second way--they raise the death. Any society wishing to avoid that result must take deliberate action to control the positive feedback loop--to reduce the birth rate.

But stabilizing population alone is not sufficient to prevent overshoot and collapse; a similar run with constant capital and rising population shows that stabilizing capital alone is also not sufficient. What happens if we bring both positive feedback loops under control simultaneously? We can stabilize the capital stock in the model by requiring that the investment rate equal the depreciation rate, with an additional model link exactly analogous to the population-stabilizing one.

The result of stopping population growth in 1975 and industrial capital growth in 1985 with no other changes is that population and capital reach constant values at a relatively high level of food, industrial output and services per person. Eventually, however, resource shortages reduce industrial output and the temporary stable state degenerates. However, we can improve the model behavior greatly by combining technological changes with value changes that reduce the growth tendencies of the system.

Then the stable world population is only slightly larger than the population today. There is more than twice as much food per person as the average value in 1970, and world average lifetime is nearly 70 years. The average industrial output per capita is well above today's level, and services per capita have tripled. Total average income per capita (industrial output, food, and services combined) is about half the present average US income, equal to the present average European income, and three times the present average world income. Resources are still being gradually depleted, as they must be under any realistic assumption, but the rate of depletion is so slow that there is time for technology and industry to adjust to changes in resource availability.

If we relax our most unrealistic assumption--that we can suddenly and absolutely stabilize population and capital, replacing them with the following:

1. The population has access to 100 percent effective birth control.

2. The average desired family size is two children.

3. The economic system endeavors to maintain average industrial output per capita at about the 1975 level. Excess industrial capability is employed for producing consumption goods rather than increasing the industrial capital investment rate above the depreciation rate.

We do not suppose that any single one of the policies necessary to attain system stability in the model can or should be suddenly introduced in the world by 1975. A society choosing stability as a goal certainly must approach that goal gradually. It is important to realize, however, that the longer exponential growth is allowed to continue, the fewer possibilities remain for the final stable rate.

Many people will think that the changes we have introduced into the model to avoid the growth- and collapse behavior mode are not only impossible, but unpleasant, dangerous, even disastrous in themselves. Such policies as reducing the birth rate and diverting capital from production of material goods, by whatever means they might be implemented, seem unnatural and unimaginable, because they have not, in most people's experience, been tried, or even seriously suggested. Indeed there would be little point even in discussing such fundamental changes in the functioning of modern society if we felt that the present pattern of unrestricted growth were sustainable into the future. All the evidence available to us, however, suggests that of the three alternatives--unrestricted growth, a self-imposed limitation to growth, or a nature-imposed limitation to growth--only the last two are actually possible.

Achieving a self-imposed limitation to growth would require much effort. It would involve learning to do many things in new ways. It would tax the ingenuity, the flexibility, and the self-discipline of the human race. Bringing a deliberate, controlled end to growth is a tremendous challenge, not easily met. Would the final result be worth the effort? What would humanity gain by such a transition, and what would it lose?

Let us consider in more detail what a world of nongrowth might be like.

We have after much discussion, decided to call the state of constant population and capital, by the term "equilibrium". Equilibrium means a state of balance or equality between opposing forces. In the dynamic terms of the world model, the opposing forces are those causing population and capital stock to increase (high desired family size, low birth control effectiveness, high rate of capital investment) and those causing population and capital stock to decrease (lack of food, pollution, high rate of depreciation or obsolescence).

The word "capital" should be understood to mean service, industrial, and agricultural capital combined.

Thus the most basic definition of the state of global equilibrium is that population and capital are essentially stable, with the forces tending to increase or decrease them in a carefully controlled balance.

There is much room for variation within that definition. We have only specified that the stocks of capital and population remain constant, but they might theoretically be constant at a high level or a low level--or one might be high and the other low. The longer a society prefers to maintain the state of equilibrium, the lower the rates and levels must be.

By choosing a fairly long time horizon for its existence, and a long average lifetime as a desirable goal, we have now arrived at a minimum set of requirements for the state of global equilibrium. They are:

1. The capital plant and the population are constant in size. The birth rate equals the death rate and the capital investment rate equals the depreciation rate.

2. All input and output rates--birth, death, investment, and depreciation--are kept to a minimum.

3. The levels of capital and population and the ratio of the two are set in accordance with the values of the society. They may be deliberately revised and slowly adjusted as the advance of technology creates new options.

An equilibrium defined in this way does not mean stagnation. Within the first two guidelines above, corporations could expand or fail, local populations could increase or decrease income could become more or less evenly distributed. Technological advance would permit the services provided by a constant stock of capital to increase slowly. Within the third guideline, any country could change its average standard of living by altering the balance between its population and its capital. Furthermore, a society could adjust to changing internal or external factors by raising or lowering the population or capital stocks, or both, slowly and in a controlled fashion, with a predetermined goal in mind. The three points above define a dynamic equilibrium, which need not and probably would not "freeze" the world into the population

Capital configuration that happens to exist at present time. The object in accepting the above three statements is to create freedom for society, not to impose a straitjacket.

What would life be like in such an equilibrium state? Would innovation be stifled? Would society be locked into the patterns of inequality and injustice we see in the world today? Discussion of these questions must proceed on the basis of mental models, for there is no formal model of social conditions in the equilibrium state. No one can predict what sort of institutions mankind might develop under these new conditions.

There is, of course, no guarantee that the new society would be much better or even much different from that which exists today. It seems possible, however, that a society released from struggling with the many problems caused by growth may have more energy and ingenuity available for solving other problems. In fact, we believe, that the evolution of a society that favors innovation and technological development, a society based on equality and justice, is far more likely to evolve in a state of global equilibrium than it is in the state of growth we are experiencing today.

Population and capital are the only quantities that need be constant in the equilibrium state. Any human activity that does not require a large flow of irreplaceable resources or produce severe environmental degradation might continue to grow indefinitely. In particular, those pursuits that many people would list as the most desirable and satisfying activities of man--education, art, music, religion, basic scientific research, athletics, and social interactions--could flourish.

All of the activities listed above depend very strongly on two factors. First, they depend upon the availability of some surplus production after the basic human needs of food and shelter have been met. Second, they require leisure time. In any equilibrium state the relative levels of capital and population could be adjusted to assure that human material needs are fulfilled at any desired level. Since the amount of material production would be essentially fixed, every improvement in production methods could result in increased leisure for the population--leisure that could be devoted to any activity that is relatively nonconsuming and nonpolluting, such as those listed above

Technological advance would be both necessary and welcome in the equilibrium state. The picture of the equilibrium state we have drawn here is idealized, to be sure. It may be impossible to achieve in the form described here, and it may not be the form most people on earth would choose. The only purpose in describing it at all is to emphasize that global equilibrium need not mean an end to progress or human development. The possibilities within an equilibrium state are almost endless.

An equilibrium state would not be free of pressures, since no society can be free of pressure. Equilibrium would require trading certain human freedoms, such as producing unlimited numbers of children or consuming uncontrolled amounts of resources, for other freedoms, such as relief from pollution and crowding and the threat of collapse of the world system. It is possible that new freedoms might also arise--universal and unlimited education, leisure for creativity and inventiveness, and, most important of all, the freedom from hunger and poverty enjoyed by such a small fraction of the world's people today.

We can say very little at this point about the practical, day by-day steps that might be taken to reach a desirable, sustainable state of global equilibrium. Neither the world model nor our own thoughts have been developed in sufficient detail to understand all the implications of the transition from growth to equilibrium.

Before any part of the world's society embarks deliberately on such a transition, there must be much more discussion, more extensive analysis, and many new ideas contributed by many different people.

The equilibrium society will have to weigh the trade-offs engendered by a finite earth not only with consideration of present human values but also with consideration of future generations. Long-term goals must be specified and short term goals made consistent with them.

We end on a note of urgency. We have repeatedly emphasized the importance of the natural delays in the population-capital system of the world. These delays mean, for example, that if Mexico's birth rate gradually declined from its present value to an exact replacement value by the year 2000, the country's population would continue to grow until the year 2060. During that time the population would grow from 50 million to 130 million. We cannot say with certainty how much longer mankind can postpone initiating deliberate control of its growth before it will have lost the chance for control. We suspect on the basis of present knowledge of the physical constraints of the planet that the growth phase cannot continue for another one hundred years. Again, because of the delays in the system, if the global society waits until those constraints are unmistakably apparent, it will have waited too long.

If there is cause for deep concern, there is also cause for hope. Deliberately limiting growth would be difficult, but not impossible. The way to proceed is clear, and the necessary steps, although they are new ones for human society, are well within human capabilities. Man possesses, for a small moment in his history, the most powerful combination of knowledge, tools, and resources the world has ever known. He has all that is physically necessary to create a totally new form of human society--one that would be built to last for generations. The two missing ingredients are a realistic, long-term goal that can guide mankind to the equilibrium society and the human will to achieve that goal. Without such a goal and a commitment to it, short-term concerns will generate the exponential growth that drives the world system toward the limits of the earth and ultimate collapse. With that goal and that commitment, mankind would be ready now to begin a controlled, orderly transition from growth to global equilibrium.