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Policy Space and System Dynamics Modeling of Environmental Agendas: An Illustration Revisiting the "Limits to Growth" Study[*]

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[*] An earlier version of this paper was presented at the Symposium on Environment, Energy, Economy: A sustainable Future, held in Rome in October 1998.

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Abstract

System Dynamics offers a powerful vehicle to model environmental agendas and design operational interventions to mitigate environmental problems, provided the models of environmental issues have in them an appropriate policy space. Two limitations mar most modeling efforts to issue operational policy: 1) The problem definition might be linked too intimately to a preferred rather than a competing set of manifestations, hence the model it creates has no way to transform behavior to an alternative manifestation. 2) The policy parameters address societal rather than individual behavioral characteristics. Hence intervention is not possible through individual motivational instruments but is implied through power or moral appeal. Using the example of the limits to growth study, this paper illustrates how those limitations affect policy recommendations and how model structure can be modified to incorporate an appropriate policy space in it so its policy recommendations are operational rather than normative.

Key words: system dynamics, environmental economics, ecological economics, environmental

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policy, energy policy, resource policy, limits to growth, computer simulation.

Introduction

Models addressing energy, resources or environment related agendas have often led to recommendations that are largely normative statements rather than operational policy instruments. Implementation of such recommendations beyond a moral appeal calls for powerful command and control infrastructure at all, local, national and global levels for which institutional mechanisms often do not exist. Powerful command and control intervention may also get divorced from the original objectives of a policy and might end up being largely driven by power considerations. System dynamics models are no exceptions to this pattern. The most influential system dynamics model addressing environmental agenda is World3 that was created for the famous "Limits to Growth Study" (Meadows et al., 1972; 1974). The main recommendations of the Limits study were to drastically limit resources use, control population and reduce pollution rate. How to accomplish those ends cannot be inferred from experimenting with the model since it is tied to a specific view point and also does not have the policy space to explore interventions for changing the behavior of the human actors in the system through feasible incentives, deterrents and services.

This paper revisits the Limits problem with a simple model incorporating the needed policy space and extends the principles learnt from the simple model to modify World3 so we are able to delineate an operational policy framework to avoid the impending catastrophe predicted by the Limits study. At the outset, the incorporation of an adequate policy space in a model requires that we look at multiple manifestations of or opposing viewpoints about future before building the model of the pattern being investigated, so there is potential structure for making a transition from one pattern to the other (Saeed, 1992). It also requires including decision rules related to the possible interventions by an agent or institution so plausible mechanisms of change can be experimented with.

The nature of the environmental agenda

The environmental issues cut across natural resources, society, economy and technology domains creating some of the most complex abstract systems of the present day world whose management is a challenge. The environmental agenda has lately become an important part of public policy. The Rio Declaration on Environment and Development (UNEP, 1992) that lead to the earth summit series was a turning point in creating awareness for the environmental issues and giving prominence to environmental policy, which has begun to be seen as an important complement of development policy. The policies currently being proposed for abating the environmental problems appear, however, to be often quite normative and sometimes even vain. Many of these policies have called for powerful exogenous intervention at the global level, although many doubts have been raised about the efficacy of such an approach. Others require substantial value change, which is equally hard to achieve. Complex systems self-regulate themselves to neutralize any interventions that do not recognize the internal tendencies arising from their structure. Also, the power institutions created to affect an intervention might move away from their original remits and work instead for maintaining their own scope (Saeed, 1996). Hence designing an implementation strategy for the environmental agendas is often a challenge.

Although system dynamics modeling is often expected to identify policies that might change system behavior by influencing the day-by-day decisions of the actors, in many cases this may not be realized, especially when a modeling exercise aims mainly at raising issues rather than designing an operational means for intervention. A case in point is the “Limits to Growth” study, sponsored by the Club of Rome to extrapolate the future consequences of the current economic growth policies. This study developed a detailed system dynamics model based Forrester’s World Dynamics (Forrester, 1971) that created insightful future scenarios but was albeit not designed to specify an operational policy guideline. When the interventions it suggested are literally translated into policy, they appear to call for a powerful exogenous intervention or a miraculous value change to limit population, abate pollution and drastically reduce resource use, for which neither an appropriate institutional structure is currently in place nor can it be created without gravely contradicting the existing systems of commerce and governance.

“Beyond the Limits”, a sequel to the “Limits to Growth” study, was published in 1992 by the authors of the original study in response to some of the criticisms of the original work

(Meadows, et al., 1992). It attempts to expand demand-side structure of the original model in an attempt to respond to the critiques of the original model, but the expanded model does not address implementation strategy beyond appeals for value change, as it still does not incorporate policy space for managing the resource and population systems to achieve a sustainable future.

The premises of an operational policy

On the basis of the underlying decision theories, the approaches to policy design can be placed in two broad categories, normative and descriptive. The normative decision theory is concerned with how people should act in order to achieve better results. It provides rules that will improve the consequences of actions. The policies formulated with an orientation of normative decision theory involve an imposition of prescriptions about social behavior decided exogenously, and often without taking into account the compatibility of such prescriptions with the existing circumstances. Due to the very nature of the premises behind the policies of this class, intervening through command and control or moral appeals are the most common strategies adopted for the implementation of normative policies. The descriptive decision theory, on the other hand, is concerned with how people actually go about handling a problem irrespective of whether the outcomes are admirable or not. This theory describes the patterns of behavior that characterize action, so it provides a simple picture of how organizations works, which is the basis for improving organizational performance (Bauer, 1968; Bower, 1968; Rappoport, 1989).

In either approach, the process of policy formulation involves several distinct steps, such as setting goals, formulating general policy directives and guidelines, identifying appropriate policy leverages and, finally, selecting policy instruments. Although the nature of the formulated policy might depend on its underlying decision theory orientations, if it fails to define operational instruments for affecting the day-by-day decisions of the pertinent actors in the system, the implementation of the policy would necessarily require powerful intervention through command and control. Unfortunately, interventionist designs are prone to failure. Firstly, it is not an easy task to achieve the needed level of centralization to implement most command and control regimes. Secondly, even when decision-making can be centralized, the actors entrusted with making the decisions may not empathize with the objectives of the design. Finally centralization may conflict with a prevalent management ideology, may be unacceptable to the members of organization in which the design is to be implemented and may invoke much conflict that is destructive (Saeed, 1996).

I have pointed out in Saeed (1994) that while it is possible to design operational policies by employing the heuristic protocol of system dynamics, this is not attempted in a large number of cases. An operational policy design should aim at mobilizing the internal forces of the system into creating functional patterns and avoiding dysfunction. Such a design can bring about evolutionary change in the system by influencing motivations of the actors that guide their day-by-day decisions. However, if this design is conceived in terms of changing a few sensitive parameters of a system dynamics model representing social rather than individual behavioral characteristics, its implementation may still require a powerful intervention by the leadership who may often neither have the motivation nor the means to commit to such an intervention, especially when the context is public interest rather than personal gain. Policy design for public agendas must, therefore, be conceived in terms of either new feedback loops that are created to modify the anatomy of critical decisions of the concerned actors or the way the influence structure of the existing feedback loops is changed so that the dominance of insidious mechanisms is minimized and the role of benign mechanisms enhanced. I have also suggested in Saeed (1992) and Saeed (2003) that a model intended for exploring policy options for system change must subsume multiple manifestations of problem behavior that are separated by time and geography since only then its underlying structure would contain the mechanisms of modal change. This means differing theoretical perspectives that often have local empirical bases should be considered as a part of the modal variety subsumed in a model addressing controversial issues.

The reference mode of the World3 model commissioned by the Limits study is based on an environmental perspective rather than subsuming the environmentalist - technologist controversy prevalent at the time it was developed (Tietenberg, 2003), hence its characteristic behavior is hard to change at the outset. The policy prescriptions of the World3 model are also based on sensitive parameters representing social rather than individual characteristics, hence their implementation appears to require powerful exogenous intervention. The revised model of its sequel, Beyond the Limits, indeed replaces some of the sensitive parameters with self-regulating feedback structure, but it is still unable to deliver adequately operational policy guidelines since, like the original model, it does not consider multiple modes implicit in the contradicting theoretical perspectives on resource policy, which are critical to creating policy space for a productive line of policy experimentation.

When run for an extended period of time, both Limits and Beyond the Limits models spell doom even when their policy recommendations are fully implemented. Hayes (1993) simulated the later model (with all prescribed policies) from 1900 through 2400. The policies, which appeared to be effective in ensuring a sustainable world, could only postpone the collapse until the middle of the 22nd century. Both models rule out any energic inputs into the global resource system that may create regeneration of resources or land, hence they cannot accommodate a line of policy experimentation that should create true long run sustainability through increasing the efficacy of the regeneration process through altering the resource basket in use. Such regeneration does occur in reality from the energic inputs received from sun, even though very slowly (Cook, 1976; Ourisson, 1984).

The nature of the policy prescription of the World3 model arises from the way the resource sectors (i.e., natural resources and arable land) have been modeled. The stocks of these resources have only outflows, which make the ultimate collapse inevitable since these outflows continue as long as there is any production supported by the remaining resources. The model does not consider any possibility of long term sustenance through regeneration, which is a widely recognized natural phenomenon that is fueled by earth’s ecosystem constantly receiving energic inputs from the sun (Miller, 1982). One could, of course, say that the fixed stocks take into account the ultimate available resources including the energy received from the sun, but the time frame of such stocks would be very different from the one considered in the Limits study. This characteristic of the model has ruled out consideration of policy options capitalizing on increasing the efficacy of the regeneration process and thus sustaining available stocks in the face of rising consumption.

Georgescu Rogan (1971) pioneered the famous hourglass model of the earth's ecosystem that draws its energic inputs from the sun, which I have tried to further elaborate in Figure 1 showing how the solar energic inputs drive the renewal process in earth's ecosystem. The resources of the earth can be placed in four aggregate categories: 1) Usable Resources, which can be expended using currently available technologies; 2) Exploitable Resources, which become usable after they have been exploited; 3) Potentially Usable Undiscovered Resources, which would later become exploitable; and 4) Spent Resources, which must be regenerated by the ecosystem to become potentially usable, or are recycled by man to be directly placed in the usable category again (Saeed, 1985). The total mass of resources in the system represented by the large rectangle might remain constant, but the proportion of usable resources within this stock will depend on the speed of circulation within the resource system, which depends on technological and management practices rather than being given for all times (Abelson & Hammond, 1974; Brooks & Andrews, 1974).

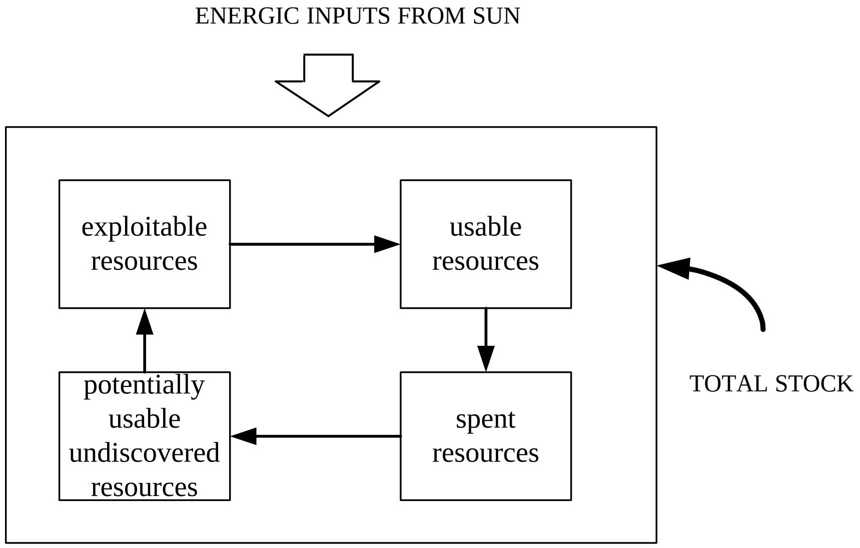

Figure 1 **An interpretation of the resource ecosystem within total resource stock.** (© 1994 Khalid Saeed. Used with permission)

A simple model of the resource ecosystem subsuming multiple views

Figure 2 shows how resources move between the four categories contained in the large rectangle of Figure 1. The expenditure rate converts usable resources into spent form and is primarily determined by the demand made on the resource ecosystem but is limited by the inventory of the usable resources available. The regeneration rate converts spent resources into the potentially usable form. Regeneration is made possible because of the energic inputs continuously received by the resource ecosystem from the sun, but regeneration time depends on the technology that determines which materials are included in the resource basket in use. Thus, the aggregate regeneration time that should be applied to this model may range between a few years to millions of years depending on the composition of the resource basket selected.

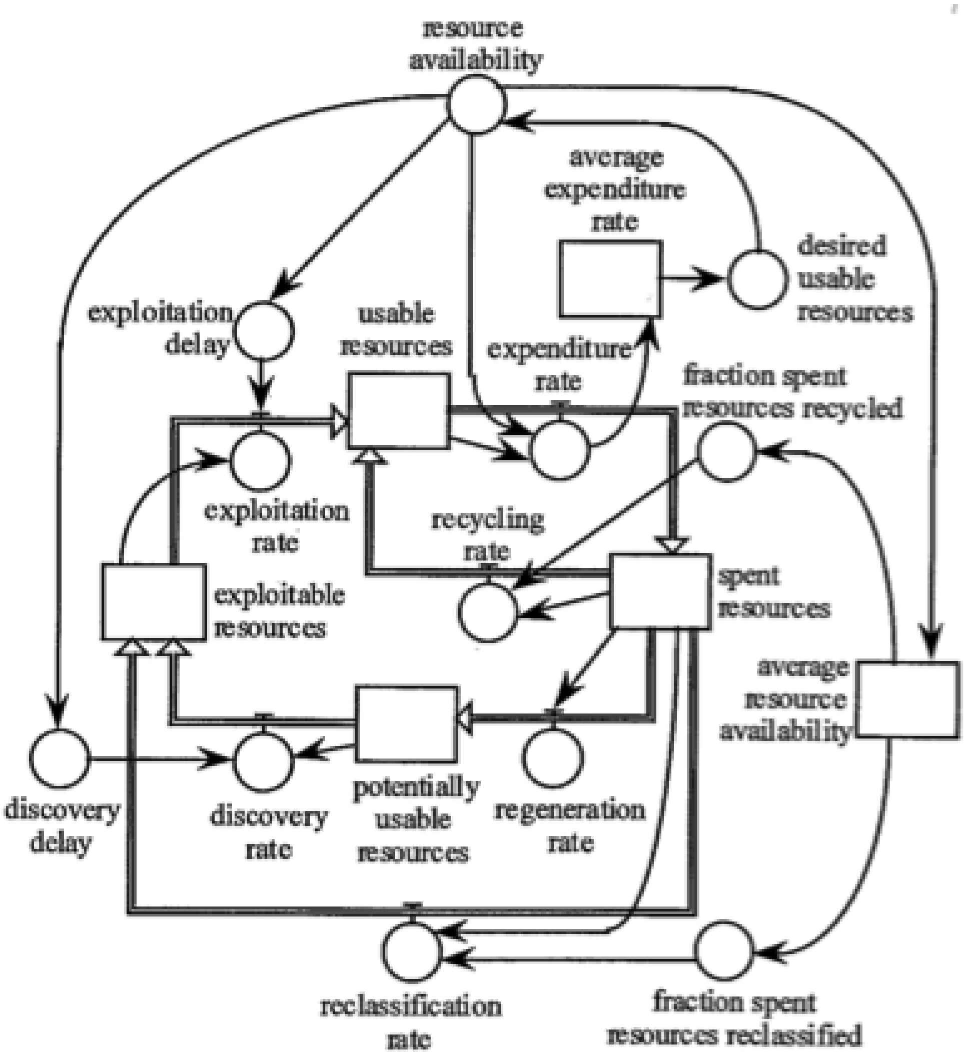

Figure 2 A simple model of the resource ecosystem. (© 1994 Khalid Saeed. Used with permission)

The discovery rate allows transfer of potentially usable resources to the exploitable category. Both, discovery and exploitation rates are speeded up if the inventory of usable resources declines below a desirable level as a condition of resource scarcity would raise prices which would draw investment into research and development of resources. A persisting condition of scarcity would also provide motivation for developing technologies for recycling and reclassifying spent resources. Recycling allows a part of the expended resources to be directly transferred to a usable form, while reclassification allows a part of the spent resources to be reclassified as exploitable.

When the demand profile is based on criteria exogenous to this model (such as a simple trend), the resource expenditure patterns produced by it will depend on the implicit assumptions made about technologies that determine the regeneration time of the resource basket in use and the rates of recycling and reclassification. Figure 3 shows a comparison of the different expenditure patterns generated when the demand profile is a simple trend.

The pattern associated with the pessimistic view results from the assumption that the regeneration time is infinitely long and there is no possibility of recycling or reclassifying spent resources. These assumptions allow a temporary increase in expenditure when demand rises, but this is followed by a catastrophic decline when usable, exploitable, and potentially exploitable resource inventories decline. At the other extreme is the pattern representing the optimistic view recognizing an unlimited supply of backstop resources (Nordhaus, 1979), which results from the implicit assumption that spent resources may always be reclassified as exploitable ones through technological advances when demand rises. These two patterns respectively incorporate implicit assumptions of the technological progress made by the environmental and the neo-classical economic models of resource use. In between these lie the patterns corresponding to the revisionist views calling for recycling and for use of fast renewable resources. These strategies result in some increases in the inventory of usable resources and thus help to alleviate a catastrophic decline in their expenditure rate, although, they are unable to match an ever increasing demand trend. Recycling, which cannot be divorced from existing production technologies, is limited to a fraction of the current rate of expenditure. Thus, it can have only a small impact. When usage is confined to fast renewable resources only, the expenditure rate is limited by the quantity and the frequency of resources in circulation. Thus, limiting usage to a narrow group of fast renewable resources may not necessarily allow society to take full advantage of the potential of the resource environment.

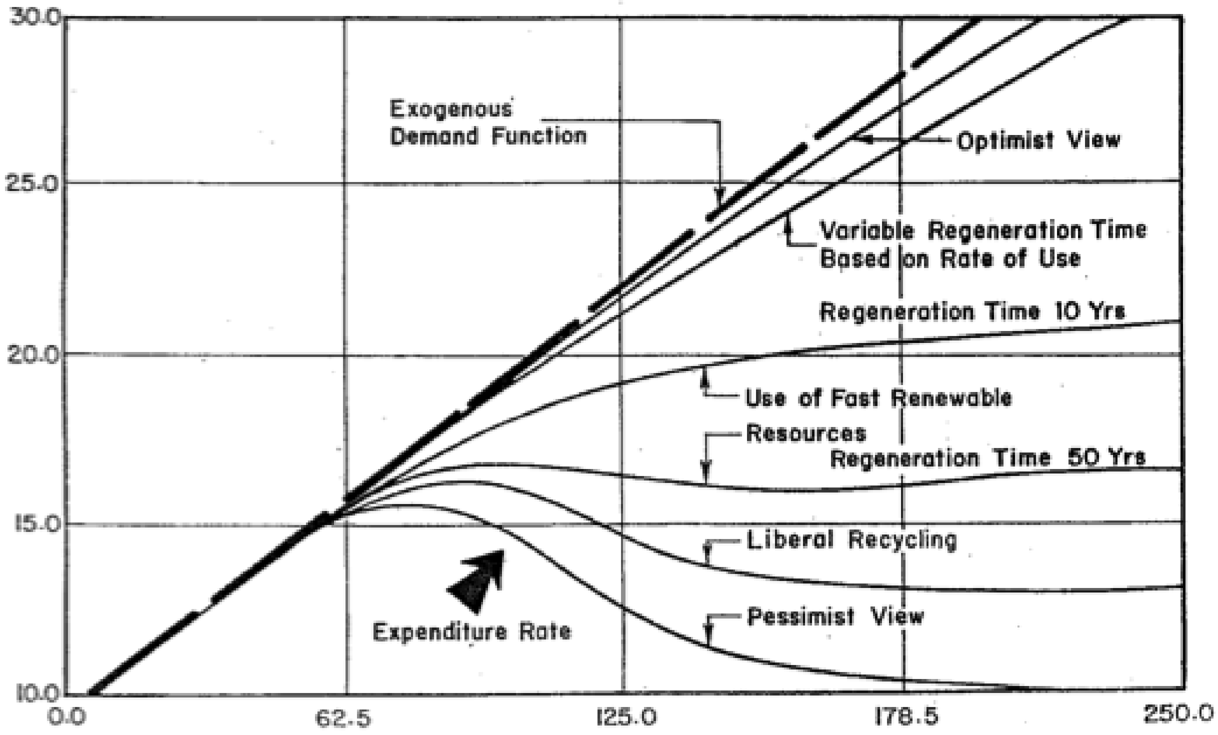

Figure 3 Resource expenditure patterns generated by the resource ecosystem model. **(© 1994 Khalid Saeed. Used with permission)**

None of the resource use scenarios discussed above appear to be satisfactory. If we expand consumption in the hope that future technologies would always make it possible to reclassify some of the spent resources into usable ones, we would be making heroic assumptions about technology and, possibly, penalizing future generations. If we make conservative assumptions about technology and show an overwhelming concern about the maintenance of the resource ecosystem, we may not only limit the benefits to the human society but also generate much conflict while implementing conservationist policies.

The resource ecosystem of the earth contains a very large variety of substances from which we can obtain materials for our consumption. Several sources for a single raw material can often be identified, although, not all of these can be exploited simultaneously since the prevalent economic criteria call for consuming the cheapest source first. The cheapest source to exploit is often the one that is richest in the materials we need for our consumption. Such resources have usually undergone the longest regeneration processing in the resource ecosystem.

It should also be noted that the distinction between renewable and non-renewable resources is a superficial one. Given enough time, all resources in the ecosystem could be renewed. Articles made from clay break and change back into clay. Metals can either directly be recycled or re-extracted from the oxides, which are formed when metals deteriorate. Metal ores are also continuously created and enriched through long-term geological processes (Cook, 1976). Plastics and man-made fibers may not be easily biodegradable, but they do not remain stable indefinitely. Eventually, they deteriorate into their simpler components, which can be assimilated by nature. There might remain an unconverted residue in a single regeneration cycle, but in each subsequent cycle, a fraction of the residue remaining from the last cycle would again be regenerated together with a fraction of a more recent batch of spent materials. Thus, most of the spent materials from a given period may ultimately be regenerated while many vintages of them may be undergoing the process of regeneration at a given time.

Similar regeneration processes also exist for energy sources other than the sun. Felled trees clear space for growing more trees. Residues from burning wood and coal fertilize land. Carbon dioxide and moisture generated from burning are used by growing plants and contribute towards the development of their cellular structure. Coal and oil are formed by nature by the destructive distillation of plant and animal cellulose. Burning of oil also deposits carbon dioxide, moisture, and waste heat in the air that help to nourish plants which, in turn, nourish animals and microbial organisms that provide cellulose for making oil (Ourisson, et. al., 1984). Radioactive metals can also be regenerated by the tremendous heat and pressure of the earth's inner core. In some of these cases, however, the regeneration process may take an incredibly long time.

The survival of human society depends not on the life of the universe but on the balancing of the consumption and regeneration of resources. If all resources are converted into the spent form and their regeneration takes a few million years, human society may not live to see the regenerated resources, while the ecosystem of the earth lives on. If we could wait for nature to complete its regenerative process on materials, it would perhaps make sense to use only the richest sources. However, such consumption could be sustained only as long as expenditure does not exceed regeneration rate. Otherwise, expenditure and regeneration will be separated by delays which human society may not survive. Thus, ideally, we ought to select a resource basket from our environment whose aggregate regeneration rate matches our consumption. When consumption rises, resources with a shorter renewal time should be added to the basket in use and those with a longer renewal time dropped from it. The remaining plot in Figure 3 illustrates implications of such a policy. As the stock of usable resources is depleted, more and more materials with a shorter regeneration time are introduced, which increases the aggregate rate of circulation of materials through the regeneration cycle of the resource ecosystem. Consequently, the stock of spent resources is more rapidly converted into the stock of usable resources. Thus, it becomes possible to sustain a higher expenditure rate. Periods of minor shortages may still be experienced, but these shortages also provide the driving force for changing the composition of the resource basket.

An ultimate limit dictated by the absolute amount of resources in the ecosystem and the maximum speed at which these can be circulated would still exist and perhaps some measure for moving towards a *steady state economy* would be in order when this limit is approached (Daly, 1974). There is, however, persuasive evidence to suggest that considerable slack exists between this ultimate limit and the current levels of consumption, provided we are able to take advantage of the variety in the resource base (Brooks & Andrews, 1973; Ravelle, 1973). The immediate need, therefore, is to facilitate technological developments which may allow to substitute the resources that have a long regeneration time constant and that are being currently rapidly exhausted, with those that are in abundant supply and that also have a shorter regeneration time constant. Technological developments that support such a flexible resource basket can be encouraged by indirect policy levers like severance taxation that raises the price of scarce resources and subsidization of technologies that support appropriate substitution rates (Saeed, 1990a).

Ironically, the opposite of this has taken place in history. As consumption pressures rose, technologies were developed to tap richer geological materials, which continued to increase the aggregate regeneration time of the resource basket in use. Such trends even led to the formulation of a very phenomenological classical theory of resource use, which postulated abandonment of low quality mines as richer mines were discovered (Robinson, 1980). Since such a historical pattern appeared because of the increasing availability of technologies that economically tapped richer resources rather than those with a faster renewable time, control of the technological progress appears to be an important entry point for implementing a sensible resource use policy.

In view of technology's unique progress in the past, the development of material resources with a shorter regeneration time may often call for reviving and refining technologies from the past when resource expenditure rate rises. Thus, future technological progress must be directed toward making possible utilization of more and more baser metals, clay, firewood, and sun and wind energy instead of more and more precious metals, fossil fuels and radioactive materials. These technological trends may, however, be reversed when adequate stocks of usable resources with a longer regeneration time have been accumulated. Such a resource use pattern may easily be realized without technological miracles, although, it may call for having a better knowledge of our resource ecosystem and a flexible end-use process. Selecting resources for use on the basis of matching their regeneration rate with their consumption rate also dispenses with an antagonistic comparison of the present with the future. Each generation may make the best possible use of the resources available to it without shifting the burden to future generations.

Incorporating pertinent policy space into the World3 model

Acharya and Saeed (1996) incorporated above considerations, albeit in a simplified form, into the base structure of the natural resource and agriculture sectors of World3. They also created additional information structure around the sensitive parameters of the model to operationalize its key policy recommendations. Their revised model included variables for the proposed policies with switches, which could be activated at any point in time. This was done to experiment with the timing of the proposed policies - to determine their sensitivity to their time of implementation, since the policies of the Limits study are time-sensitive while timing in a system with rough parameters cannot clearly be discerned. The Acharya & Saeed (1996) revision of the World3 model, thus, consisted of two stages - the revision of the base model to accommodate controversial perspectives on resource policy and to create latent structure for a possible equilibrium, and the structural additions representing policy implementation agendas. The revisions made are described below:

Revision of natural resources sector

Natural resources sector is one of the five principal sectors of World3. “Nonrenewable natural resources” is the only stock in this sector in the original model. The nonrenewable resources are defined as mineral or fossil fuel commodities essential to industrial production. They are regenerated by nature on a time scale that is very long compared with the 200-year time horizon of the model (Meadows et. al., 1974). The initial value of the natural resources stock is fixed in the original model and the only rate connected to it is the out-flowing usage rate, meaning that no part of the resources can be renewed. In terms of the physics of the resources, this really implies that the composition of the resource basket is fixed with the aggregate regeneration time being much longer than the time frame of the model. This structure rules out any policies influencing the resource basket and the technological progress that should support a flexible resource basket as suggested in Saeed (1985) and Saeed (1990a). To remedy this limitation, a resource regeneration structure is incorporated into the model in which the regeneration time depends on the composition of the resource basket in use that is in turn determined by the technological choices dictated by the prices of the available resources.

Figure 4 shows the additional information structure Acharya & Saeed (1996) added to World3 in their revision of the resource sector. At the outset, a provision for resource regeneration is introduced in the model. Implicit sources of regeneration are the geological processes, recycling, and substitution from the pool of backstop resources which contrary to their definition are not assumed to be unlimited. The revised structure incorporates active as well as latent feedbacks. First, it has been assumed that market imperfections are removed to enable the market signals to create appropriate feedbacks. The market clearing mechanism has, however, not been explicitly modeled as the level of aggregation of World3 did not allow this. Instead, the price adjustment is assumed to be responsive to resource availability. The price level thus transmits appropriate signals to the technological progress related to substitution, recycling and use of natural resources.

The price system discussed above can, however, only ensure intra-temporal efficiency of resource allocation. So, to ensure inter-temporal equity, indirect intervention through the provision of a severance taxation system was added. Such a severance tax structure should assure that consumption and regeneration rates are matched through an appropriate selection of the resource basket. This requires continuous monitoring of resource use rates and resource stocks to determine coverage time for each stock, which is translated into its availability. The severance tax is then continuously adjusted in response to resource availability assuring in the long run that there are no inter-generation transfers of cost.

The severance tax simultaneously influences the recycling rate, the substitution rate (from the stocks of the backstop resources), the efficiency of use and the indicated level of industrial production and the regeneration time constant (determined by the composition of the resource basket in use). The technological dimension is implicitly included in each of these influences. Hence, one of the premises of the revised structure is that technology can be influenced endogenously through severance tax. As all newly created feedback loops are of balancing nature, the advancement in technology is automatically guided towards sensible choices cognizant of environmental considerations.

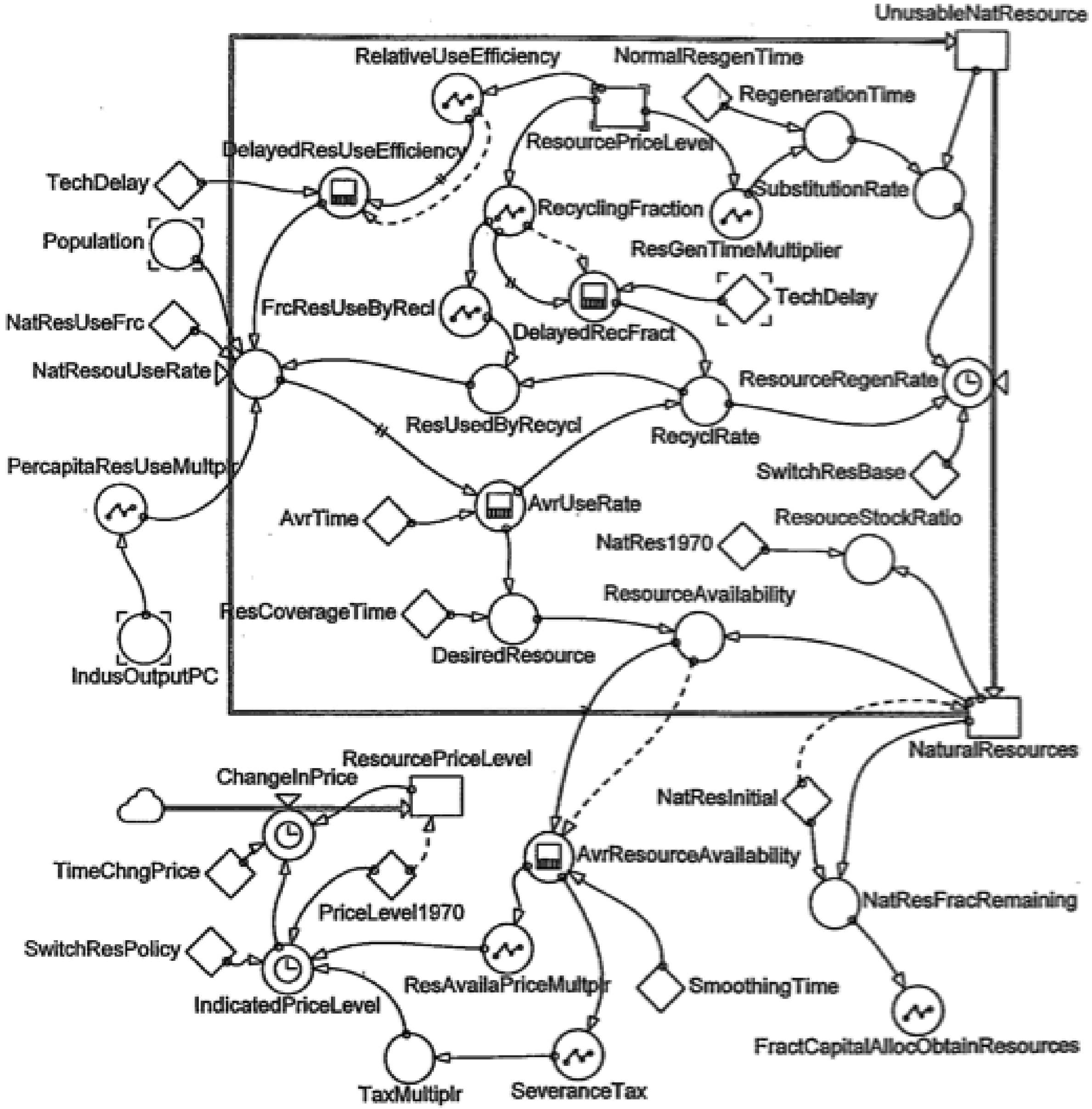

Figure 4 Flow diagram showing revisions of the resource sector of World3. (© 1996 Surya Acharya & Khalid Saeed. Used with permission)

The severance tax mechanism also acts to limit the expansion of the capital sector. In the original

World3 model’s policy package, the desired per capita industrial output was exogenously restricted to 320 units in 1990. With the introduction of the severance tax provision, we can see that the desired industrial output must respond to the level of tax through the pricing mechanism.

The policy levers affecting the resource basket built into the model are based both on the principles of neoclassical economic theory and the physics of the resource ecosystem. The neoclassical economic theory advocates using natural resources to maximize the present utility determined by market situation, discount rates and technology in use, which are subsumed in the price responses built into the model. The price mechanisms are, however, good only for assuring intra-temporal efficiency of resource use and they cannot address the issue of inter-temporal equity (Pearce et. al., 1989; Page, 1977). Because, according to the theory of market economy, reserving resources for future use makes sense only when the expected future price of the resources is increasing, at least, at a rate equal to the market rate of interest. However, the market rate of interest generally exceeds the rate at which the society wishes to discount future. Hence, the market mechanisms always favor the present use of resources over the future use, which does not serve the societal interest in terms of inter-temporal equity (Solow, 1974). To address the problem of inter-temporal (or inter-generation) distribution of natural resources, variable severance taxation also based on current resource availability is introduced in the model as a proactive policy lever that Solow (1974) and Page (1977) have favored.

Revision of agriculture sector

In the original Limits model, as in the case of natural resources, the arable land has been treated as a fixed stock without any possibility of regeneration. It is subjected to continuous erosion even when food production is declining. This structure is responsible for an inevitable decline of food production. The revised model of the Beyond the Limits study does not make any changes to introduce the structure for land regeneration, which ruled out exploring any policy experimentation concerning land management. In reality, fallow practices have been used for ages to regenerate land fertility. There are also well known land management practices involving crop rotation, planting and soil management methods that facilitate natural soil conservation and regeneration processes. Even in a precariously balanced desert environment, the nomads of Sahel have been able to maintain a reasonable level of soil fertility for an extended period of time before their agricultural system was disturbed through so called development effort (Picardi & Siefert 1976).

Figure 5 shows the additional information structure created in the Acharya & Saeed (1996) revision of the agricultural sector of World3. As in the case of natural resources, they added structural components to the land stocks to provide for land rehabilitation. This change on one hand corresponds to the real world situation, as there are cases of rehabilitation of eroded land in the past, while on the other it also creates additional space for exploring operational policy. The related policy prescriptions translate into enhanced efforts for land rehabilitation or regeneration through technological development or extension programs the extent of which is linked with the eroded land fraction.

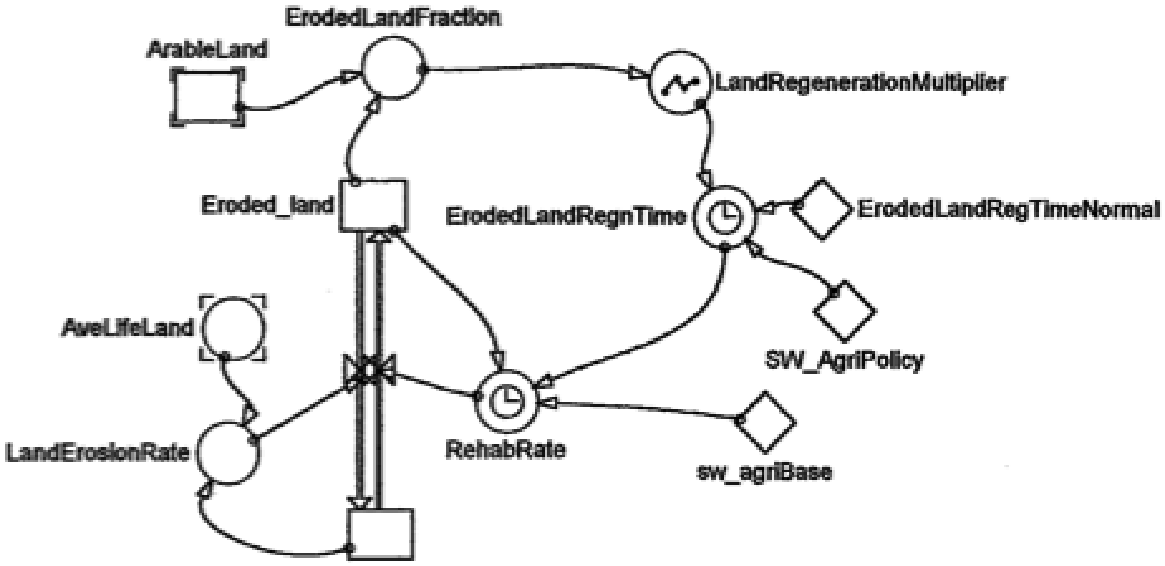

Figure 5 Flow diagram showing revision of the agricultural sector. (© 1996 Surya Acharya & Khalid Saeed. Used with permission)

Revision of other sectors

The only other changes Acharya & Saeed (1996) make in the remaining sectors of the model (population, capital and pollution) are in terms of constructing new information links from the respective stocks to the policies based on the information residing in them and connecting those polices to the flows affecting the related stocks.

Population sector determines fertility and life expectancy. The Limits study identifies the desired completed family size as a sensitive policy parameter in this sector. In World3 model this variable is influenced only by industrialization, which is consistent with the classical theory of demographic transition. However, recent work on the political economy of fertility reveals that industrialization was not the sole reason for demographic transition experienced in the industrialized countries. There is substantial historical evidence designating government policy interventions as the primary cause for the fall in fertility rates. The so-called “soft” government policy has often governed private micro-level decisions of the reproductively active adults in many of the advanced industrial nations (Ryan, 1991). Demeny (1988) perceives such soft and indirect policies to create a gravitational field of services, incentives, rewards and penalties, that with a minimum of specific intervention would shape individual demographic behavior so as to best harmonize conflicting individual interests.

Figure 6 shows the feedback mechanisms created by the soft interventions implied above into the population and pollution sectors. Information relationships reflecting the effects of industrialization and the level of social service delivery influence family size as these factors are known to affect individual decisions on desired family size through lifestyle changes. The provision of such services is, however, not free but is achieved at the cost of reductions in industrial output per capita.

In pollution sector, the policy option considered entails the development of pollution abatement technology. An information link has been established between Persistent Pollution Index and Required Level of Pollution Abatement Technology. This structure reflects the need for continuous monitoring of pollution level, which is a basis for developing a corresponding level of pollution abatement technology. Needless to add that in reality this would entail development of institutions entrusted with the tasks of monitoring and policy formulation.

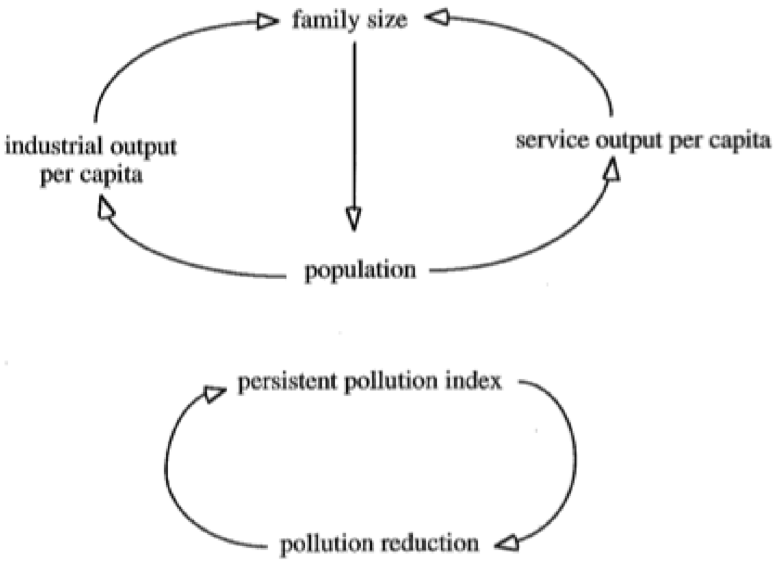

Figure 6 Feedback loops created by the proposed pollution reduction and population planning policies in the revision of World3. (© 1996 Surya Acharya & Khalid Saeed. Used with permission)

Figure 7 shows the feedbacks entailed in the Acharya & Saeed (1996) revision of the capital sector. The main policy objective in the capital sector is to stabilize industrial growth, which can be accomplished by influencing the decision to invest and which eventually determines the level of industrial output. The condition of natural resources availability and persistent pollution are the key stocks responding to the investment policy. Desired level of industrial investment is also regulated through varying the investment in social services sector. This policy objective can be achieved through indirect government intervention, for example through fiscal instruments influencing the investment decision and regulations for industry to provide or contribute to social services. The volume of adjustment to be made in the industrial output determines the extent of indirect intervention needed.

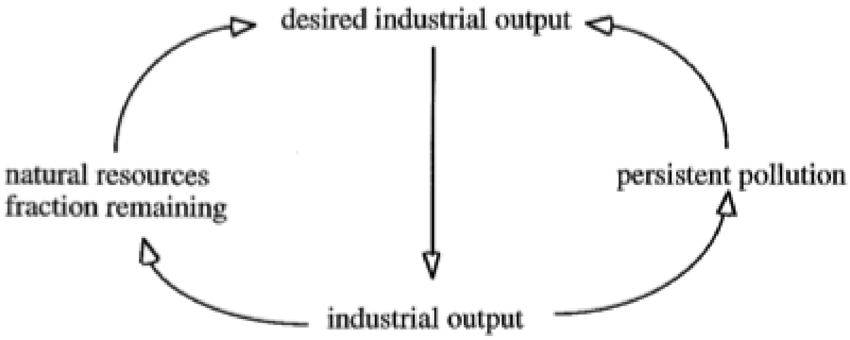

Figure 7 Feedback loops created by the proposed industrial stabilization policies. (© 1996 Surya Acharya & Khalid Saeed. Used with permission)

Policy experimentation with the revised model subsuming policy space for resource management, social services and pollution abetment.

Figure 8 shows the base run of the Acharya & Saeed (1996) revision of World3 model obtained by activating the revisions made in the base model modifying its natural resources and agriculture sectors in year 1900, but without activating any policy instruments built into it. The system still exhibits the characteristic behavior of overshoot and collapse, although the collapse is deferred for some time. This occurs because the introduction of market mechanisms with a regeneration provision in the resource sector of the model takes the pressure off the usable resource stocks to a limited extent. Ultimately, resource base starts dwindling rapidly since regeneration falls much short of consumption. The resulting resource crunch makes the population go down with all indices of standard of living declining. These results show, however, that even if a perfect market is established for the natural resources, it is not possible to alleviate resource scarcity in the long run as widely believed in the postulates of traditional resource economics.

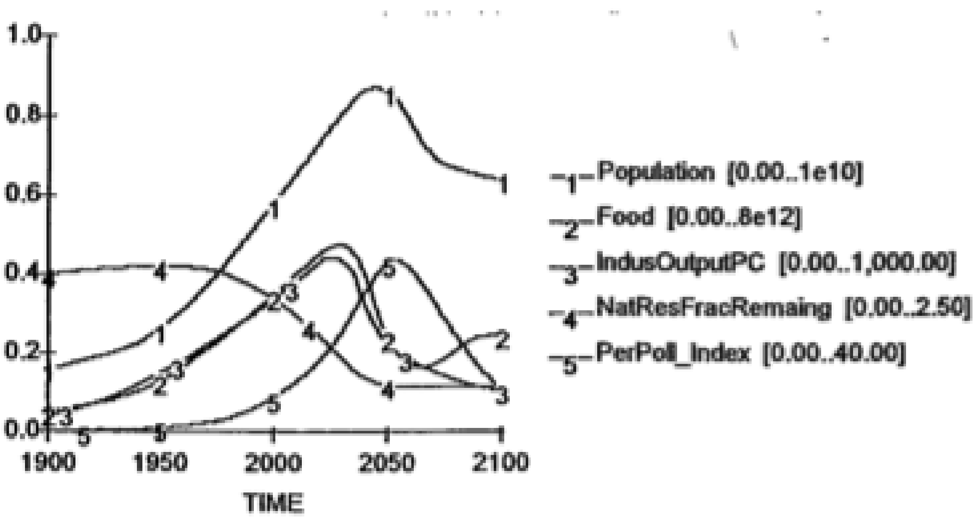

Figure 8 Base simulation run of the revised model. (© 1996 Surya Acharya & Khalid Saeed. Used with permission)

Simulation run with severance tax and its influence on technological progress

Figure 9 shows the behavior when the model is simulated with the additional policies of clamping severance tax on the scarce resources and making technological progress responsive to resource scarcity as I have suggested in Saeed (1985). The model structure corresponding to the severance tax and technological policy are activated in the year 1975. The severance tax policy pushes the resources price higher than that determined by the market, which simultaneously stimulates substitution, recycling and efficiency of use technology. These policies do not alleviate the problem of collapse, however, since when resource constraint is removed, the industrial growth is accelerated resulting in excessive pollution. Thus, the excessively high level of pollution created by the accelerated industrial growth (supported by the resources stock) is now responsible for the collapse.

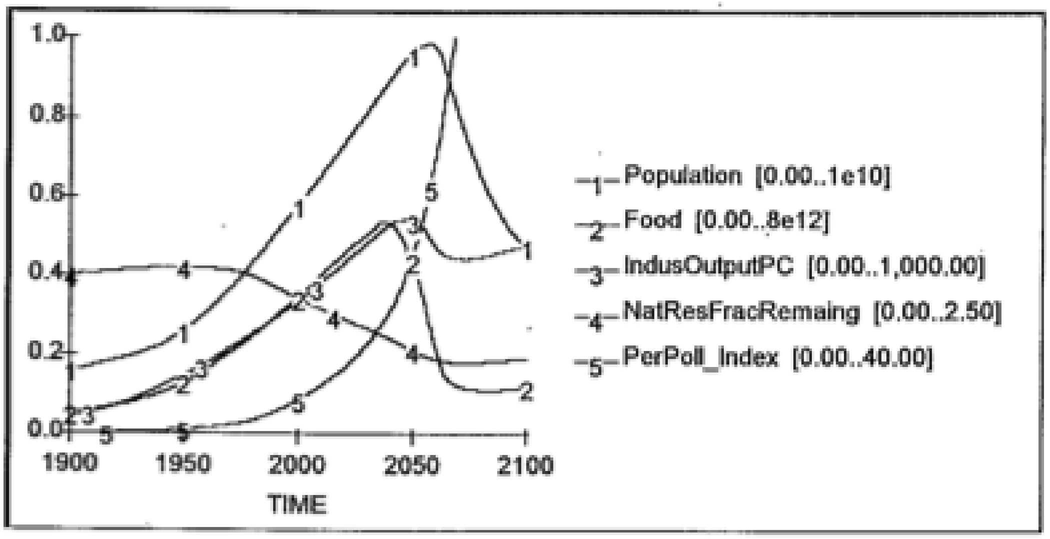

Figure 9: Simulation run with severance tax and technology policy seeking to adjust regeneration time of the aggregate resource basket in use. (© 1996 Surya Acharya & Khalid Saeed. Used with permission)

Simulation run with pollution, industrial output stabilization and population policies

The industrial output stabilization policy attempts to maintain an indicated level of industrial output by influencing the society’s decision on investment for social services. The desired level of industrial output is continuously adjusted in response to the level of persistent pollution and the stock of natural resources through indirect interventions, such as taxation. If the level of industrial output is more than desired, more investment is diverted to social sector and vice-versa. This influences investment trends in the industrial sector and eventually stabilizes the industrial output at around the desired level. This simulation also incorporates the impacts of the level of industrial output and social services on population, that reside in the links created in the revised model from industrial output per capita and service output per capita to desired family size.

Figure 10 shows a simulation run when pollution, industrial output stabilization and population policies were activated in 1975. In order to see the long run effectiveness of policies, simulation was performed until the year 2400. In this run, the problem of excessive pollution seems to have been alleviated by the pollution reduction policy, which was achieved by activating the information link between Persistent Pollution Index and Required Level of Pollution Abatement Technology. The model behavior is significantly improved with the introduction of these policies, at least, in the short run. However, if the behavior is carefully scrutinized, it can be seen that the system is not perfectly stabilized. In particular, food production heads for continuous decline, which could cause a collapse in the long run.

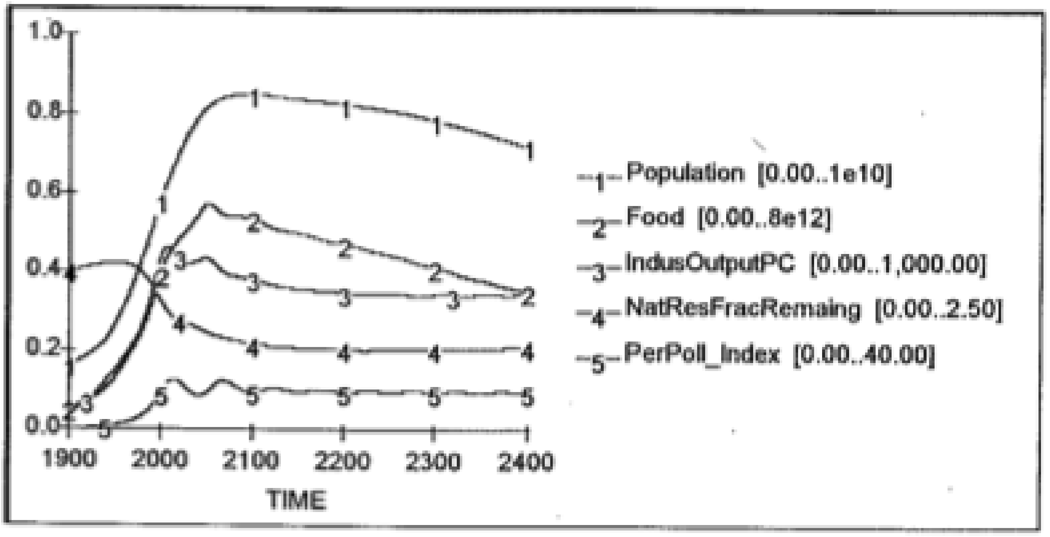

Figure 10 Simulation with industrial stabilization, population planning and pollution reduction policies added to the policies of Figure 9. (© 1996 Surya Acharya & Khalid Saeed. Used with permission)

Simulation run with land regeneration policy

Finally the model was experimented with land regeneration policy activated, which speeds up the regeneration of eroded land and checks the decline of food production, together with all policies of the previous run activated in 1975. The resulting simulation is shown in Figure 12. With this policy package the model is robustly stabilized in the long run.

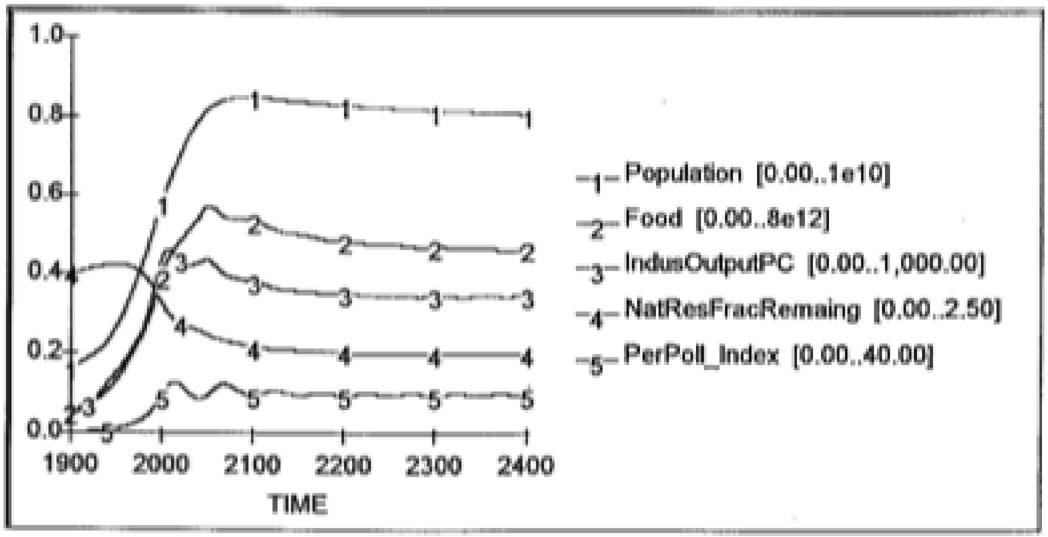

Figure 11 Simulation with land erosion control mechanisms added to the policies of Figure 10. (© 1996 Surya Acharya & Khalid Saeed. Used with permission)

Path dependence of the proposed policy framework

In the previous simulation experiment a policy package consisting of severance tax, technological progress responsive to resource availability, pollution reduction, land regeneration, industrial output stabilization, and population planning could bring the system into equilibrium when implemented in the year 1975. The same policy framework is now activated in the years 1995 and 2015 in order to test the path-dependence of the proposed policy framework. Table 1 shows the equilibrium value of the key variables with different timings of policy package introduction. Each of the simulation runs not only exhibits a stabilized behavior but also yield little variation in equilibrium value of the key variables. Since an equilibrium goal now exists in the latent structure of the revised model, it should be possible to achieve this goal into the future by activating the necessary feedback elements with a wide range of initial conditions present at the time of policy implementation.

Table 1 Equilibrium values of the key variables when the proposed policy package is implemented at different point in time.

Variables	**End equilibrium values of variables**		
Year of policy introduction	**1975**	**1995**	**2015**
Population	8.0E9	8.2E9	8.85E9
Food	3.7E12	3.7E12	3.7E12
Industrial output per capita	346.5	341.6	336
Resource fraction remaining	0.5	0.5	0.5
Persistent pollution index	3.8	3.9	4.0

A potential equilibrium goal must always be carefully discerned in all models seeking to stabilize the systems they represent. In the absence of such a goal, adequate operational policy space for stabilization will not exist, which has been the limitation of World3 model and its sequel, although these models were quite adequate for understanding the nature of the problem and identifying pressure points for change. Without such a goal, all conceived policies will be path dependent since their impact will be limited to a narrow range of time frames and also sensitive to the starting conditions.

The implementation process

Sustaining world resources and environment is a global problem, which in common sense perception, should be addressed by a global order. Experience shows, however, that in an economically and politically polarized world, any global order would further power interests rather than promote collective welfare. Hence, solutions for global problems may often not reside in global orders. The Limits study has made a valuable contribution to sustaining mankind by bringing to fore the issues, which are widely seen today as critical to our existence. It should also be credited with raising those issues almost a quarter of a century ago, when little awareness existed about them. The policy agenda it raised, however, could be considered only in the context of a global order or a radical value change, both of which are difficult to realize

Seeking operational means for implementing the recommendations of the Limits study attempted by Acharya & Saeed (1996) creates a possibility for achieving global sustenance through local means. Their proposed policy package can be easily implemented through fiscal instruments and institutions, existing as well as potentially feasible, within the framework of national orders. This means global coercion and its accompanying problems can be avoided. However, in a world intimately connected through information, trade flows and financial interaction, local implementation of these policy recommendations might also become difficult to follow. There is a need to explore operational means also to sustain global relations, although through local instruments, which is a significant challenge for research on sustainability and a fertile area for system dynamics to pursue further (Pavlov et al., 2005; Saeed 1998; Choucri & Berry, 1996).

Conclusion

The policies affecting environmental agendas often not make a distinction between individual and societal behavior. While individual behavior can be changed by manipulating motivational instrument, a society may not have unified goals that might offer a similar entry point. Models that deal with societal rather than individual parameters will lack decision space for any operational policy design and thus would issue either merely moral statements or call for powerful exogenous intervention for changing societal norms and values.

The environmental agendas have often commissioned models that lack operational policy space for creating recommendations that can be implemented within an existing institutional framework. The limits to growth study is a case in point as its key recommendations were to limit population growth, reduce resource consumption drastically, and stop polluting the environment. How should these recommendations were to be implemented could not be stated without building additional policy space in the model.

The Limits to Growth study made a valuable contribution to knowledge on sustainable development in bringing to fore the implications of indiscriminate growth at a time the environmental capacity was often perceived to be unlimited. It also correctly identified the critical entry points for sustaining mankind in a finite resource environment. Beyond the Limits, a sequel to the Limits study attempted to further enrich the original Limits model by internalizing mechanisms of technological development and also by refining agenda for action proposed by its precursor. The models of the Limits study and its sequel Beyond the Limits were, however, not designed for experimentation to seek operational policy and a verbatim interpretation of their recommendations appears to spell radical value change or draconian action at the global level, which are seen to be both infeasible and counter-productive. There has clearly been a need to carefully examine the operational implications as illustrated in this paper.

Models addressing environmental agendas should take into consideration pertinent structure that should allow manipulating parameters relating to individual behavior rather than to social characteristics in the management of environment. Furthermore, multiple modes of behavior subsuming opposing views should be considered while constructing models for policy intervention so mechanisms for changing from one mode to the other could be explored. Thus both technologist and environmental views of future should be considered as multiple modes constituting the reference mode. Only then a model will allow exploration of operational policies for change.

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