MODELLING SUSTAINABLE DEVELOPMENT IN SCOTLAND

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Abstract

This paper describes a dynamic simulation model of sustainable development for strategic resource management drawing upon research in Scotland. Section two presents a brief over view of sustainable development and the types of measures that can be used in national or smaller scale studies. Section three describes a dynamic simulation model of sustainable development integrating aspects of ecology namely natural capital (Kn) and human welfare (Km) into the one framework. The model casts Scotland in the context of the global system. The global and national models capture many features of the current trends 1970-1990 of unsustainable development for example population growth, employment, poverty, trade and environmental impact measures. This section briefly reports on some scenarios which local government and non-government organizations are seriously considering as the basis for sustainable development strategies in Scotland. Finally, some future developments of this model are described which will lead to four dimensional modeling i.e. the integration of a three dimensional geographical information system driven by a dynamic simulation model.

1. INTRODUCTION

Since the publication of "Our Common Future" (WCED 1987) - often referred to as the Brundtland Report - there has been great interest shown in the concept of sustainable development. The Brundtland Report gave many definitions of the concept and the most quoted one is that "sustainable development requires meeting the basic needs of all and extending to all the opportunity to satisfy their aspirations for a better life .... sustainable development requires that promotion of values that encourage consumption standards that are within the bounds of the ecologically possible and to which all can reasonably aspire .... at minimum, sustainable development must not endanger the natural systems that support life on Earth: the atmosphere, the waters, the soils, and the living beings" (WCED, 1987, pp. 44-45).

Over the last decade there have been numerous publications which have amplified or developed this definition and over 100 definitions of the concept can be given (Pearce et al, 1989: Moffatt, 1996). This paper briefly describes some of the measures associated with the concept of sustainable development. In the following section it will be demonstrated that using seven different measures Scotland is currently unsustainable. There is, therefore, a need to alter current socio-economic practices to move an unsustainable Scotland onto a sustainable path. One way of demonstrating this is to develop models of sustainable development. Section 3 describes a dynamic multi-sector model of sustainable development in Scotland. The model attempts to capture some of the important aspects of the ecology and economy of Scotland along with several measures of sustainable development. The model tracks the unsustainable nature of Scotland and then illustrates the ways in which policies can be introduced to move the model onto a sustainable trajectory. Finally, some areas of research which are currently being pursued are discussed.

2. MEASURING SUSTAINABLE DEVELOPMENT

There are many definitions of sustainable development and each one stresses certain aspects which were given in the Brundtland Report (WCED, 1987). The debate over sustainable development has moved on from discussions over definitions of the concept to examine the ways in which sustainable development can be measured (Azar et al, 1996; Pearce, 1993; Moffatt, 1996; Atkinson et al, 1997). A useful early environmental impact measure included population, resource consumption and technology. The new measures include green Net National Product (gNNP). biological Net Natural Productivity (NPP), ecological footprints and Indices of Sustainable Economic Welfare (ISEW). This section uses an early and simple model to measure the magnitude of human impact on the environment drawing upon Ehrlich and Holdren method (Ehrlich and Holdren, 1971). This is followed by noting the ways in which more elaborate indicators give details for Scotland (for full details see Hanley, Moffatt, Faichney and Wilson, 1998)

Twenty six years ago a simple model of the impact of hunman activities on the ecology of an area was given by the equation

$$I = P*C*T \quad \textbf{equation 1}$$

where I is the environmental impact, P is human population, C is consumption per capita and T is the technology. Equation 1 can be re-written in several forms but the original paper suggested that a percentage change form is useful shown in equation 2

$$(1+dI/I) = (1+dP/P)*(1+dC/C)*(1+dT/T) \quad \textbf{equation 2}$$

where dI, dP and dT represent changes in population, consumption and technology respectively. The advantage of using the equation 2 is that it is possible to calculate the percentage increase in say population by multiplying dp/p by 100 .An increase of 100 represents a doubling of the initial population an increase of 200 per cent a tripling , and so on. In the original paper the authors examined automobile lead emissions from 1946-1970 for the USA.. By using equation 2 the overall impact was 5.15 and the relative importance of each component of the equation was population 1.42; consumption 2.00 and technology 1.81. The key point noted in the original work was to show the contribution that population and affluence as well as technology had on the growth in lead emissions in the USA (Ehrlich and Holdren, 1971).

Applying the same method to the global pattern of environmental impacts it is possible to examine the changes required in technology , population growth and consumption patterns to reduce environmental impacts by say 50%. By dividing the world into the rich North nations and the poor South then the patterns of population (P), consumption (C) and technological change (T) can be revealed. Ekins and Jacobs have demonstrated the following results

1 Unexceptionably, with no growth in P or C then T must be reduced by 50%

2 Growth in P, and no growth in C reduction in T by 65%

3 Growth in P and growth in C in South reductions in T by 81%

4 Growth in P, growth in C in the North reduction in T 89%

5 Growth in P and C in North and South reduction in T by 91%

It should be noted that the pattern of rapid population growth in the South actually has less impact on the planet, in the short run, than increased consumption by those in the North which represent 5 per cent of the world population. Ekins and Jacobs note that the unchallenged aspiration that demographic and consumption patterns can grow in both the North and South require an improvement in technology of 91% (Ekins and Jacobs, 1994). They also note that a 91 % improvement in technology must be seen as a fantastic change even by the most ardent technological optimist.

At the national level a whole series of new measures of sustainable development have been derived. At least seven measures have been empirically determined in the case of Scotland. These measures are the General Progress Index (GPI); the Index of Sustainable Economic Welfare (ISEW); Net Primary Product per Capita (NPP/K); Environmental Space (ES); Ecological Footprints (EF) ; Genuine Savings Index (GSI) and an Approximate Environmentally-Adjusted Net National Product (AENP). From these seven national measures only one measure (AENP) showed increasing sustainability ALL the other measures showed that Scotland was unsustainable if current patterns of consumption continued (Hanley, Moffatt, Faichney and Wilson, 1998). It is against this sombre empirical background at both the global and national scales that attempts to model sustainable development in a realistic but simple manner must be made.

3. A MODEL OF SUSTAINABLE DEVELOPMENT FOR SCOTLAND IN A GLOBAL SETTING

Given the numerous definitions and measures of sustainable development it is clear that there are many different ways of translating these ideas into models of sustainable development. A model is a simplification of a real world system which captures some aspects of the processes underlying that system. Most model builders are familiar with models of atmospheric change or of hydrological phenomenon. In these and other cases the real world system provides data of the system under investigation and the model builder attempts to replicate significant aspects of the behavior of the real world. In many aspects of environmental science and science in general the approach adopted is *positivistic*. In systematic studies into sustainable development the emphasis is upon altering an unsustainable system and attempting to develop strategies which would allow the unsustainable development to be turned around and a pattern of sustainable development to be introduced. In this sense modeling sustainable development is *normative* and introduces ethics and politics values explicitly into the equations. It is against this background that many models of sustainable development have been developed (Faucheux et al, 1996).

One of the problems of modelling sustainable development is to recognize that any one country is part of the global economic system. Whilst an individual country's impact on the world environment may be small it is not negligible but the impact of global changes in say climate or economic matters will have an impact on any nation. Hence, if we are to realistically model sustainable development for Scotland, Australia or any nation it has to be set in the context of the global economic-ecological system. This of course poses immense problems for any model builder as it is difficult to model the macroeconomy-ecology of a nation let alone place the nation in its global setting. The approach adopted here is to first develop a global model which captures some but not all of the interactions implicit in the WCED definition of sustainable development and then sets a national model in this context.

From the empirical analysis presented earlier it is clear that the current pattern of consumption globally cannot be sustained especially when one considers that a doubling of the global population is anticipated. The Rich nations are already above the upper sustainability level i.e. we are unsustainable and probably passed this limit sometime in the recent past. The poor South appear to be moving into possible sustainable areas although some countries within this group are already considered as well below sustainable patterns of living and need aid. Finally, there is no single path of sustainable development - the actual path depends on a wide range of assumptions, beliefs and actions.

The simple world model simulates the global environmental impact of population and resource changes. The model runs for three hundred years simulated time and solves the equations for every year. At its simplest the model is divided into three sectors -a demographic group, a "biosphere" and a materials sector. The demographic sector recognizes that the worlds total population can be divided crudely into a rich 20% and a poor 80%. Both demographic sectors change by rates of birth and death. The major difference in the structure of the two demographic groups is that the rich group experience falling birth rate as their wealth expands. This is consistent with observation of several rich nation as captured in the demographic transition model. More recent research has indicated that in wealthy nations birth rates fall as the citizens become richer. In the poor South sector the birth rates are high as poverty causes individual families to produce more children even though the chances of survival are lessened per child. Both population groups are supported by food taken as a minimum to represent the FAO kilocalories per person per day converted into tonnes of Net Primary Productivity (NPP) per person per year . Whilst there are many reasons for the differences between the poor and the rich, for example, resource endowment and level of technology we suggest that the main problem is due to trade.

It is well known that any society needs to derive its sustenance from the use of renewable resources. In the model the renewable resources or " food supply" is taken from the Net Primary Productivity (NPP) of the globe. In 1986 Vitousek et al suggested that current human consumption of NPP accounted for 40% of the total and noted that two further doubling of the world population will. on current rends, be physically impossible to achieve (Vitousek et al, 1986). In the model we constrain the human appropriation of NPP by an upper limit of 50% although this, like any other parameter, can be changed. The NPP sector remains in a state of dynamic equilibrium and attempts to compensate for human appropriation of food from this level. It should be noted that NPP represents the total food supply of the planet and that includes the food supply for ALL living forms.

Economic growth and development is also predicated upon the use of nonrenewable resources. The conventional view is to make a distinction between nonrenewable energy resources (oil, natural gas and uranium) and other nonrenewable (metallic minerals, aggregates etc.). In this model all the material in the Earth's crust is potentially available for use as materials inputs into the economy. This includes all known nonrenewable energy resources and other minerals. Obviously not all of the Earths' crust could be used but it represents another finite amount of materials taken as the total amount of rock down to the 45 km below sea level. The model assumes that the two populations groups have differential access to the per capita consumption of these materials set at 2 and 10 tonnes per person per year for inhabitants of the poor and rich nations respectively. Again, current patterns of (unfair?) trade are assumed to keep this differential access to the use of nonrenewable resources unless policy changes are made to the terms of trade. The pollution generated by the use of nonrenewable resources is given a conservative figure of 50% material consumed per person per year. It should be noted that the pollution generated in the model only impacts directly onto the life support system of the biosphere as the pollution index increases then death rate of NPP increases.

It is very clear that the global model is relatively simple - indeed it was designed to be simple so that the environmental impacts globally of resource use and population change could be examined. The environmental impact (I) is the same as used by Ehrlich and Holdren but in an index form. An index has to be used as different forms of pollution and environmental degradation are measured in different units and cannot be combined. The base run assumes no major changes to the structure of world trade or policies so it represents a business as usual scenario. The total population initialized at 5 billion in 1970 increases to 18.6 billion before becoming extinct in 2200. The rich population increases from 500 million to 601 million whereas the worlds poor increase from 4.5 billion to 18 billion. During the simulation the worlds poor actual become twice as badly off compared with the 1970 figure. The main cause of collapse of the human population is food shortage due to the destruction of the biosphere by 2200. It will be recalled that the amount available for human consumption was set conservatively as 50% (currently we extract 40% of NPP) and during the simulation the food requirements per capita actually meet the FAO minimum requirements for every person. In short if business as usual continues then we have less than 250 years to save the planet. So is it possible to make policy changes which could lead to a sustainable world and if so what policies would be effective? We will return to these questions after examining the model of Scotland.

Compared to the rest of the world Scotland is a small nation. It population circa 1970 was 5 million in an area of 78,829 square kilometres. These figures represent some 0.1% and 0.015% of the 1970 global figures used in the world model even today the population of Scotland has remained quite stable at 5 million. We are then dealing with a small rich nation but it is clear that Scotlands impact on the globe may not be as strong as the impact of the global environmental and economic changes on Scotland.

There are four main differences between the national model and the global model. First, the demographic sector includes in and out migration. Next, a more detailed sector on employment is incorporated. Third, changes in world prices are included rather than purely material flows. Fourth, different land use categories (representing important aspects of renewable resources) can be incorporated. Obviously, the model can be further dissagregated to reflect the details of any national economic and environmental statistics. It is important that the dissaggregation does not mask the three main aspects of the models structure which are non-renewable and renewable resources and demographic interactions. The national model is then initialized with the relevant data for 1970, the beginning of the simulation, and the model is run to stay within the constraints of the global model. Obviously, these global constraints must be observed as the summation of all nations resource use will add up to total global net primary production and nonrenewable resource use.

The full details of the dissagregated model will be described elsewhere (Moffatt, Hanley, Faichney and Wilson, 1998). For present purposes we can report that the model simulations are consistent with and statistically significant with the real data - although the model is only initialized for the year 1970. The model runs for 300 years and the patterns of development using several different measures also reflects the empirical patterns of unsustainable development examined earlier (Hanley, Moffatt, Faichney and Wilson, 1997).

The results give us some confidence in the model that we are on the right lines of developing a robust model of sustainable development and one which can be applied at different spatio-temporal scales and has application well beyond Scotland. There is, however, the need to examine ways in which the current unsustainable path that Scotland (and the World) follow can be altered by implementing policies to ensure a sustainable path for current and future generations.

To illustrate one of the many scenarios a policy designed to reduce resource consumption's patterns was used. It will be recalled that the global analysis suggested that changes in resource consumption of up to 91% are required to contribute to a sustainable world. In the Scottish example we reduce resource consumption by 25% and this results in prolonging the timespan of humans living in Scotland. It will be recalled that the recent history of Scotland has a stable population -which is very unlike the global situation. In the latter context it is clear that combined policies to control population growth, resource consumption and therefore pollution generated must be implemented together and introduced quickly - at least if we are to make development sustainable. These alternatives are currently being examined in this research.

4. CONCLUSIONS: FUTURE RESEARCH IN MODELLING SUSTAINABLE DEVELOPEMNT

Despite the considerable progress in modelling sustainable development that has been made since the publication of the Brundtland Report (WCED, 1987) it is clear that more research remains to be undertaken. Several avenues for future research may be suggested both for the research community involved in modelling sustainable development, for strategic environmental policy making and for computing technology.

The current generation of sustainable development models are quite crude. Some at present are not capable of being used as forecasting tools; others are developed for use but lack a sound theoretical base. The model described in this paper is, we contend, both theoretically sound and is applicable for making a contribution towards strategic policy making. It needs much further sectoral disaggregation and this will inevitably bring problems with data availability. There are also some other important avenues which need to be developed. In particular the integration of the dynamic models with a three dimensional geographical information system (GIS) still needs further development. Costanzas work is probably the best development in this field but is used for simulating continuous variables such as the spread of water and the spatio-temporal diffusion of pollutants in an estuary (Costanza, 1997). In cases where discrete parcels of land use are being planned then more sophisticated solutions have yet to be devised. The integration of three dimensional dynamic models to address the problems of discrete and continuous variables within the one model framework would appear to be the next step in this research in to modeling sustainable development.

From a policy perspective it is quite clear that discussions with policy makers in Australia and Scotland see the need for exploring sustainable scenarios which explicitly examine both the temporal and spatial development of a system. Many environmental managers and strategic policy makers are ill at ease with dynamic models which lack a spatial or a geographical representation of the "real world". To actually model spatio-temporal changes in ecological-economic interactions often requires access to supercomputers. It should, of course, be noted that the scenarios generating changes through time or space or both are only guides to possible futures - they are not predictions in a strict scientific sense but are probably the only way we can examine the longer term consequences of our actions which have important implications for both current and future generations (HMSO, 1994).

Finally, any developments in the field of computer based modelling of sustainable development is obviously linked to the wider developments in computer based technologies. The development of supercomputers and parallel processors can give more power to the model builder but these technological developments are only a necessary condition for the production of really useful models of sustainable development. Other developments in say data base handling, remote sensing and intelligent knowledge based systems can perhaps contribute to the goal of making development sustainable. Even if the power of modern information technologies were applied to this fundamental problem it should be noted that sustainable development can not be resolved from a purely technical perspective - although this will undoubtedly help the process. It should, however, be noted that such optimism for technological development is not to be confused with, or used as a substitute for, making ethically sound and politically accountable judgments to enhance the life opportunities for future and current generations on Earth.

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