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A GENERAL DYNAMIC ECONOMIC-ECOLOGICAL MODEL FOR REGIONAL SUSTAINABLE DEVELOPMENT.[+] [++] [+++]

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Abstract.

This study focuses attention on sustainable development of a region by analyzing with a dynamic model the long term behaviour of an open economic-ecological system for various relevant scenarios. We mention reasons for studying the concept of regional sustainable development, discuss its meaning and implications, and characterize models based on this concept. The model used here includes descriptions of: (1) economic activities, (2) economic dynamics, (3) economic balances, (4) ecological functions, processes and dynamics, (5) material balances, (6) feedback mechanisms from the ecological to the economic system, and (7) inequality constraints. The description of the ecological dynamics is based on general ecological functions and characteristics. The ecology-economic feedback mechanisms provide for the possibility of studying various degrees of concern for future generations. Simulation is used to obtain insight in the behaviour of the system under different policies and strategies. To gain insight into regional sustainable development various scenarios are analyzed. They include the use of environmental policies of waste treatment, recycling, research and development, and environmental cleaning. Others are strategies for the use of regenerative resources, allocation rules for extraction of renewable and non-renewable resources, and strategies for satisfying dynamic waste emission standards. The model allows also for analysis of impacts of high and low investment, and variations in the domestic relative to the foreign price level. A few scenarios are discussed in more detail. Finally, a table is shown in which some of the scenarios are evaluated with respect to performance in terms of proposed criteria for regional sustainable development.

1. Introduction.

The concept of sustainable development is - particularly since the publication of the Brundtland report (WCED, 1987) - increasingly referred to in integrated economic-ecological analyses (see Archibugi and Nijkamp, 1989). This concept reflects a compromise between the aim of economic growth and concern for the environment. It recognizes the basic goal of survival of the human species, the long term goal of realizing an acceptable quality of life for each individual in present and future generations, preservation of diversity and quality in the natural environment, and a wise management of natural resources and ecosystems. 'Sustainable' implies that the necessary conditions for some dynamic phenomenon to take place are structurally satisfied. Bearing this in mind, the following definition of ecologically sustainable economic development is used here: the development of economic activities, human behaviour and human population, such that an acceptable standard of living for every human being now and in the future is ensured (the phenomenon) and all aspects of this development can be fulfilled in the long run by natural resource availability, ecosystems and life support systems (the necessary conditions) (see van den Bergh and Soeteman, 1990).

In the next section we discuss sustainable development in a regional system. The general implications for models to be used for analysis of sustainable development are discussed in section 3. In section 4 a general aggregate dynamic model is formulated for studying regional sustainable development. Finally, simulation results with this model are given in section 5.

2. Sustainable Development in a Regional System.

The quality and quantity of environmental production factors is a dominant factor with respect to the comparative advantage of a region and may critically influence its pattern of economic growth and development. When restrictive environmental law and policy in a given area is absent polluting and resource-using activities may be attracted. They usually will stimulate economic growth in the short run but not necessarily in the long run because they can cause severe environmental damage. It has been argued that especially regions with energy resources or an important agricultural sector may exhibit a strong growth in income levels, in contrast to regions dependent on external energy sources, many of which have shown strong growth in the past because of low energy prices (Miernyk, 1982).
We introduce here the concept of a regional resource base which can be defined as the complex of resources and their regenerative systems that are critically important for regional welfare through regional economic activities or direct uses by the regional population. A regenerative system supports the existence and regenerative capacity of a renewable resource (from Opschoor, 1987). Various types of regional economic dependencies on the regional resource base can be distinguished, for example use of regional resources in regional production, export of regional resources, export of services based on the availability or accessibility of a specific regional geographical resource, local recreation based on regional cultural goods, and a regional resource sector having significant impacts on general economic activity in the region.

We start the discussion of regional sustainable development (abbreviated hereafter as RSD) by presenting an extended definition:

> Regional sustainable development is the change over time in the region of culture, technology, demographic structure and migration, governmental institutions and policy, the level and composition of private economic activity and cross-boundary flows, that is compatible with: (a) a continued existence of the region's life-support systems, maintaining the regenerative capacity of its renewable resources, an efficient use of its non-renewable resources, pollution below assimilative capacity levels, the ecological disturbance below threshold levels, and a preservation of species diversity, (b) an acceptable standard of living for each individual in the region, (c) intergenerational equity, and (d) a globally sustainable development.

Consequently RSD should satisfy two goals: (1) it should ensure an acceptable level of welfare for the regional population, which can be maintained in the future; (2) it should not be in conflict with sustainable development at a supra-regional level. Constraints for any regional development, including RSD, may emerge from the initial state of the regional economic and ecological system and the external determinants of internal development.

Sustainable development requires a kind of balance in terms of quality and quantity of flows between economic and ecological systems. In addition to this type of balance RSD may be considered to require a balance in terms of flows of regional imports and exports in the long run, for both ecological physical flows and trade monetary flows. This may satisfy the conditions for attaining a globally sustainable development. The flows mentioned are determined by socio-economic activities like trade, capital flows and migration (see foregoing section). If one concentrates only on economic and ecological cross-boundary flows and economic-ecological interactive flows, one may formulate an operational model in which allocational efficiency - one element in RSD - can be dealt with. Although this view is interesting, it is still too narrow. RSD includes intergenerational equity considerations as well as non-monetary and non-physical flows of services provided by environmental resources.

The definition states explicitly that RSD for a single region is compatible with global sustainable development. Consequently, if all regions of a global system have a RSD, then the development in the global system will be sustainable as well, by way of condition (d) in the definition of RSD. Clearly, the RSD paths of specific regions may have different characteristics because of specific regional circumstances (e.g., availability and use of natural resources and socio-economic capital, environmental vulnerability and resilience, and socio-economic distribution of income and employment), so that it is not easy to typify RSD in general.

Given the existence of trade, transport, dispersion of species, or other socio-economic and ecological linkages between regions, it may of course be possible to attain sustainable development at a global level without having a RSD path at the regional level. In extreme cases it might even be possible that global sustainable development demands regional 'sacrifices' to the detriment of regional development (or environmental sustainability). Such a development may be acceptable from a supra-regional or global human needs perspective. By 'sacrifice' we mean here a reduction in welfare for the regional population, which will be in contrast to the first above mentioned goal that RSD should satisfy. This may happen, for instance, when certain regions are used for specific environmental or economic purposes (such as conservation of natural areas, concentration of industrial activity, or dumping of waste). According to the Brundtland-report (WCED, 1987, p 45) it is even not realistic to suppose that every ecosystem (which may encompass more than one region) can be preserved intact everywhere. In these cases we have to look for regional implications of SD or constraints of SD for RSD, which may ask for solutions to the difficult problems of regional compensation, which will not be dealt with in this paper. The other direction in linking RSD to SD is to look into the supraregional implications of one region's development not being sustainable.

For most regions the approach to attain RSD includes the sustainable use of natural renewable resources in the region. This applies mainly to renewable stocks of natural resources and reflects the idea that the use of goods and services provided by such stocks can be arranged to maintain some optimal stock level and some optimal rate of use that is not subject to fluctuation. If a stock of renewable resources is used in this sense, it may generate a flow of materials and/or services for an unlimited period of time. If this flow is sufficient for generating an acceptable welfare level for the regional population ('sustainable welfare'), it is clear that one should aim at a conservation of the resource. Thus resource management is a critical variable, as overuse or extinction of a resource is in most cases an irreversible process. Moreover, wise management of the resource guarantees at least that for a long time (part of) regional income is ensured. Sustainable resource use may then provide an appropriate starting point for RSD. However, sustainable use of a region's stock of resources may be regarded as an important - though not sufficient or even necessary - condition for RSD . Such a preventive strategy should be regarded as a kind of risk-avoiding strategy. An acceptable standard of life, among others based on man-made goods, intergenerational equity, etc. should be balanced with respect to sustainable resource use.

3. Models for Sustainable Development.

Which specific type of model is relevant for gaining insight into sustainable development issues, or for tracing sustainable development paths? This crucial question may be tackled by studying the following list of considerations, which can be used to typify such models. Some of them will make it possible to distinguish specific models for sustainable development from other models that are used for dealing with general economic-environmental problems. These considerations are:

1. an integrated - in contrast to a partial - approach;
2. presence of a feedback from the ecology to the economy;
3. inclusion of intergenerational interests;
4. possibility of describing qualitative (structural) changes;
5. inclusion of finiteness of available material and energy resources;

6. limitations on substitution, technological progress and population growth; and
7. openness of the economic-ecological system.

The need for integrated modelling is based on the idea that partial approaches, with restrictive ceteris paribus conditions, are likely to become less relevant when considering long term horizons; instead of specific sector-resource interactions, the entire economic structure with both productive and non-productive uses of the environment should be included; a general description of the natural environment should therefore be included as well. Inclusion of feedbacks of ecological impacts of general economic activity to the economic system is essential for an adequate description of long term processes in economic systems; then it is possible to deal with the phenomenon of ecosystems providing economic systems with dynamic physical constraints (and potentials); feedback also occurs via perceived resource scarcity or real exhaustion, and via perceived pollution levels or environmental quality to decisionmaking with respect to productive activities. Long-term interest also calls attention for the well-being of future generations; clearly, this requires a judgement criterion to be chosen for the evaluation of intergenerational distributions; various conditions may be included in models which constrain or regulate intergenerational distributions (e.g., on natural capital, pollution or economic capital); in a descriptive model this consideration also means that a long time horizon is chosen for, so that short term processes are excluded as much as possible; furthermore, the long term horizon calls for scenario analyses to include many uncertain elements. Structural change may refer to irreversible processes (e.g., investment in man-made capital, development of natural areas), thresholds (e.g., in population evolution), behavioral time-delay functions, or micro transitional processes (e.g., sectoral interactions, or technological processes); this consideration, together with the third one, implies the possibility of non-linear structures (linearization is only allowed if a short period of time or small changes are studied). The two main laws from thermodynamics - and especially the materials-balance law - may be relevant in ensuring consistency in modelling physical - economic and ecological -interaction processes. There are limitations regarding substitution possibilities, and hence adequate restrictions on the specification of welfare and production functions have to be specified; alternatively, endogenous relationships may be included to explain simultaneously the evolution of two events, e.g. the growth in technology and in population; furthermore, interdependencies between substitution of production factors, investments and technological progress have to be carefully considered, in view of the emphasis of technology in growth debates. Since economic systems are influenced by external forces and since many cross-boundary flows arise from spatial economic and ecological processes, openness with respect to imports and exports of goods and services, technological progress, and ecological cross-boundary flows should be elements in models for RSD.

4. A General Aggregate Economic-Ecological Model for Regional Sustainable Development.

4.1. Introduction.

In this section a general economic-ecological model for analyzing regional sustainable development is presented. This model differs from many other economic-environmental models (see for overviews

Ayres, 1978 and Barbier, 1990) in several ways. Firstly, it describes the long term dynamics of complete economic and ecological systems and the interactions between them. Secondly, it includes monetary/physical balances and materials balances with regard to flows and transformations of resources, goods, waste and pollution. Thirdly, it describes the feedback from ecology to economic behaviour and allows for the inclusion of varying degrees of concern for future generations. Fourthly, it describes the cross-boundary flows to and from the economic and the ecological systems.

We ignore any repercussions that the economy may have on the rest of the world, so that we are dealing with a one-region model. If one wishes to describe a region which impacts considerably upon the rest of the world (a 'large region') a two-region model should be used (describing the 'large region' and the rest of the world). The model describes the material flows in the economic and ecological systems and between them. Monetary assets and price mechanisms are not considered. Markets are assumed to be in equilibrium continuously. The model uses a stock-flow structure, to include dynamic processes in a logical/causal framework. The model is supply-oriented, which is also reflected in the choice of a long-term horizon. A list of stock and flow variables, as well as of functions and parameters is included in appendix A.

4.2. Economic Activities.

The region's output Q is produced by means of capital K and resource inputs R_Q. A higher quality of the environment E and a higher cumulative total of R&D outlays T_{rd} are assumed to affect the production efficiency positively. Scarcity of resource inputs is reflected via an indicator for shortage in resource supply R_{short} , while waste strategies are possible via W_{sust}. The latter two variables will be discussed more extensively in section 4.7. The total perceived availability of resources R_{sup} (see also section 4.7) provides - together with the resource input requirement per unit of output c( ) - for an upper limit to produced output. Furthermore, it is assumed that the level of output is determined by production capacity and resource availability restrictions, and that the ratio Q/R_Q is changed through technological progress. So we can write[1]:

$$Q = \min\{ F(K,E,R_{short},W_{sust}) \ , \ R_{sup}/c(T_{rd}) \}, \qquad (1)$$

$$R_Q = c(T_{rd})^*Q, \qquad (2)$$

with all partial derivatives of F( ) are non-negative. Output Q cannot exceed input R_Q and some part of the resource input to production will not end up in the output Q, so that c( )>1. Technological change is assumed to generate more efficient production processes in terms of a lower ratio of R_Q to Q, so that $dc/dT_{rd}<0$.

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[1] Notice that labour is not included, so that it is implicitly assumed that long term development of production is not restricted by labour supply. A dynamic equation for population however is included in order to allow for per capita indicators.

The amount of waste treated R_{wa} is determined by the level of waste from production W_Q and the outlays for waste treatment activity O_a. Similarly, the amount of recycled resources R_{rec} is determined by the waste flow suitable for recycling W_{rec} and the outlays for recycling activity O_{rec}:

$$R_{wa} = f_a(W_Q, O_a), \tag{3}$$

$$R_{rec} = f_r(W_{rec}, O_{rec}). \tag{4}$$

All partial derivatives of f_a and f_r are non-negative. The above description of economic activity concentrates on aggregate production and two environmentally beneficial activities and is useful for studying the flow of resources as well to and from as within the economic system.

4.3. Economic Dynamics.

The change in the capital stock depends on the investment level and the rate of depreciation, which in turn is related to the present level of capital. The investment level is determined by the internal investment I and the inflow of capital investment I_m. The stock of capital depreciates at a rate given by D(K) ($\partial D/\partial K>0$):

$$dK/dt = I + I_m - D(K). \tag{5}$$

The population change is determined by the present number of people Pop, the level of material consumption per capita C and net immigration Migr:

$$dPop/dt = B(C/Pop)*Pop + Migr. \tag{6}$$

$dB(x)/dx$ is non-positive for developed regions. The (non-material) cumulative amount of R&D outlays T_{rd}, serving as an indicator for technological progress, increases with such outlays in the region (O_{rd}) and external inflow of R&D-knowledge, indicated by $O_{rd,m}$:

$$dT_{rd}/dt = O_{rd} + O_{rd,m}. \tag{7}$$

Furthermore, the stock of treated waste S_{wa} accumulates as a result of waste treatment activities:

$$dS_{wa}/dt = R_{wa}. \tag{8}$$

The latter equation does not affect other processes and is just added for completeness. The initial conditions are $K(0)=K_0$, $Pop(0)=Pop_0$, $T_{rd}(0)=0$, $S_{wa}(0)=0$. The economic dynamics is thus taken rather broadly here, namely to include capital accumulation, population growth, and technological progress.

4.4. Economic Balance Equations.

The economic system is open, so that the sum of regional production and imported output (Q and Q_m) equals the sum of produced consumption goods C_Q, regional investments I, total (governmental) spending O on environmentally beneficial activities, and export of output Q_x:

$$C_Q + I + O + Q_x = Q + Q_m = Q_{tot}. \tag{9}$$

Total regional income is Q_{tot}. Export is assumed to depend on the domestic price level relative to that abroad, denoted by P_{rel}:

$$Q_x = f_{Qx}(P_{rel}), \tag{10}$$

where $\partial f_{Qx}/\partial P_{rel} > 0$.

Import is assumed to depend on Q and P_{rel}:

$$Q_m = f_{Qm}(Q, P_{rel}), \tag{11}$$

with $\partial f_{Qm}/\partial Q > 0$ and $\partial f_{Qm}/\partial P_{rel} < 0$. In a more extended model P_{rel} can be defined as the domestic price level divided by the foreign price level times the exchange rate. We assume here that P_{rel} is exogenously given. Expenditures on environmentally beneficial activities are allocated between treatment, recycling, cleaning, and R&D (O_a, O_{rec}, O_c, and O_{rd}, respectively). These are financed from regional income (O) and supraregional subsidies (O_m). The latter may be relevant in a multiregional country or community.

$$O_a + O_{rec} + O_c + O_{rd} = O + O_m. \tag{12}$$

Material consumption C consists of regionally produced commodities C_Q and resource consumption C_R.

$$C = C_Q + C_R. \tag{13}$$

Resource consumption is either a free variable or linked to the level of produced consumption per capita, in the following way:

$$C_R = f_{CQ}d(C_Q/Pop)*Pop, \tag{14}$$

with $\partial f_{CQ}(y)/\partial y \leq 0$.

4.5. Ecological Functions and Characteristics.

A general aggregate ecological model should be consistent with a macroeconomic or regional system in terms of geographical coverage. Therefore, it should have a global character, i.e. describing the essential features of a collection of various (possibly interacting) homogeneous ecological systems. Such a general model would have to be able to deal with the following functions and characteristics of ecological systems: (1) regenerative capacity, (2) assimilation of pollution, (3) resource generation, (4) non-material services for consumption, (5) decreasing performance of all functions for higher levels of pollution and congestion, and (6) possibility of irreversible development as a result of too much pollution or a high extraction rate. Ecological (internal) functions - such as regulation, reserves-keeping, transport of water, minerals and seeds - cannot be represented in such an aggregate model (at least not explicitly).

We propose - in view of the six mentioned ecological functions and characteristics to be included in our general ecological model - the following simple dynamic aggregate structure as a suitable representation of a large scale (national or regional) ecological system:

$$E = H(N,P,Pop,O_c), \tag{15}$$

$$dN/dt = G(N,E) - R_N, \tag{16}$$

$$dP/dt = -M(P,E) - P_x + W_{em}, \tag{17}$$

where the following conditions hold:

$N(0)=N_0,\ P(0)=P_0,$
$0\leq H(N,P,Pop,O_c)\leq 1,$
$\partial H/\partial N \geq <0,\ \partial H/\partial \delta P<0,\ \partial H/\partial Pop<0,\ \partial H/\partial O_c \geq 0,$
$G(N_{min},E)=G(N_{max},E)=0,$
for some (N,E), with $N_{min}<N^*<N_{max}$, $E>0$: $G(N^*,E)>0$, and
$\partial G(N,E)/\partial E \geq 0.$

E is an indicator for environmental quality that depends on the regenerative resource capacity N, the stock of pollution P, the congestion indicated by the population level Pop, and the outlays for environmental cleaning activities O_c. The regeneration of the resource is given by G( ), which depends on the present stock of resources and the environmental quality. N_{max} denotes the maximum amount of regenerative resources (also referred to as carrying capacity). The assimilation function M( ) depends on the present level of accumulated pollution, and the environmental quality. Regional cross-boundary flows of pollution are described by outflow (P_x) of pollution and inflow of emitted waste (contained in W_{em}).

This ecological model includes the exogenous variables - originating from an economic module: - 'outlays for environmental cleaning'(O_c), an indicator for the level of (various types of) pressures or disturbances (Pop), resource extraction (R_N), and waste emissions (W_{em}). An exogenous variable not determined in the economic module is the cross-boundary pollution flow P_x. Non-renewable resources are not included in this framework, since we assume that they are independent from the 'regenerative environment' in a direct sense. This general ecological module allows us to construct an aggregate dynamic model in which an economic and ecological module are connected in such a way that a closed form model is obtained which represents - in a simple, consistent and balanced structure - the most important processes and interactions (both ways).

The non-renewable resource dynamics are represented by

$$dS/dt = -R_S, \tag{18}$$

with initial condition $S(0)=S_0$. S denotes the present stock of non-renewable resources, and R_S denotes the extraction rate.

4.6. Material Balance Equations.

The production activity gives rise to a material balance equation, as the amount of resource input R_Q equals the material goods output Q and the waste output W_Q from production, or:

$$W_Q = R_Q - Q. \tag{19}$$

The total resource input of the production process R_Q equals the sum of newly extracted amounts of renewable and non-renewable resources R_{Qn} and the amount of recycled materials R_{rec} which is only used for production (i.e., it cannot be used for consumption directly). Therefore, the demand for newly extracted resources is equal to

$$R_{Qn} = R_Q - R_{rec}. \tag{20}$$

The total demand for the regional resource is the sum of regional productive needs R_{Qn}, consumptive needs C_R, and export of resources R_x:

$$R_{dem} = R_{Qn} + C_R + R_x. \tag{21}$$

R_x depends on the domestic price level relative to the foreign price level:

$$R_x = f_{Rx}(P_{rel}), \tag{22}$$

with $\partial f_{Rx}/\partial P_{rel}<0$. The waste suitable to be recycled equals the sum of depreciated capital D(K), consumptive waste C, and other (material) outlays O. It is assumed here that waste arising from production cannot be recycled (or is implicitly included: recycling which increases efficiency in terms of a lower ratio of waste output to resource input of production):

$$W_{rec} = D(K) + C + O. \tag{23}$$

The total waste, before waste treatment and recycling, equals the sum of production waste W_Q and recyclable waste W_{rec}:

$$W = W_Q + D(K)\ W_{rec}. \tag{24}$$

The waste emission level W_{em} equals the total waste before waste treatment and recycling W minus the amounts of treated and recycled material waste (R_{wa} and R_{rec}), plus the import of emitted waste ($W_{em,m}$), less the export of emitted waste ($W_{em,x}$):

$$W_{em} = W - R_{wa} - R_{rec} + W_{em,m} - W_{em,x}. \tag{25}$$

Export of waste is a fraction of total domestic waste emission:

$$W_{em,x} = c_{em,x}{}^{*}(W - R_{wa} - R_{rec}) \tag{26}$$

The distinction between $W_{em,x}$ and P_x (see in ecological dynamics formulation) is motivated by the idea that waste emitted in the region may either leave it without harming the regional ecological system (or, if you wish, bypassing it), indicated by $W_{em,x}$, or first enter the ecological system, add to the stock of pollution (P) (and thus negatively affecting environmental quality (E)), and then leave the region (e.g., through flows of groundwater or rivers).

4.7. Feedback from Ecology to Economic Behaviour: Inclusion of Intergenerational Concern.

The total perceived available amount of resources as inputs to the economic processes of production and consumption depends on the ethical stance with regard to future generations and is given by:

$$R_{sup} = f_{sup}(N,S,G). \tag{27}$$

The function $f_{sup}(\ )$ may be specified as the sum of N and S (no concern for future generations), or the sum of S and G (sustainable use), or the sum of p*S ($0 \le p < 1$) and G (much concern for future generations). The variable R_{short} indicates whether the consumptive and productive demand for newly extracted resources can be met by the above mentioned perception of supply:

$$R_{short} = f_{short}(R_{sup}, R_{dem}). \tag{28}$$

This function may be specified for instance as $\min\{1, r^*R_{sup}/R_{dem}\}$, with r a safety margin. r less than 1 indicates a high degree of safety, a value 1 complies with a neutral attitude and higher than 1 denotes little carefulness. In this case, R_{short} is zero when demand and supply are equal, and takes positive values otherwise. R_{short} returns in the production function to impact negatively on production when its value indicates a perceived shortage and neutrally otherwise.

The foregoing shows how concern for the well-being of future generations can be expressed via the perceived available amount of resources. For a feedback from pollution to economic behaviour the following approach is taken. The goal is given in by concern for future generations and may vary from net decay of the stock of pollution to zero growth (sustainable waste emission) or even a certain positive rate of waste accumulation. In the case of sustainable waste emission the following simple equation controls the feedback of pollution stock accumulation to production:

$$W_{sust} = f_{wsust}(dP/dt, P, M, Wem). \qquad (29)$$

A possible specification is $\min\{1, m^*M/W_{em}\}$ with m a safety margin which in the case of sustainable waste emission is less than 1, and in the case of an allowed positive rate of accumulation in the stock of pollution may be higher than 1. The smaller m, the more careful the economic behaviour towards negative ecological consequences.

4.8. Inequality Constraints.

These include non-negative conditions on all stock and flow variables, and all functions in the model. Also extraction rates should not be higher than the level of the stock from which extraction is taking place. The total extraction of resources should not be higher than their demand, while - under a given allocation schedule of extraction - total extraction should be as high as possible (i.e., equal to or minimizing the difference with the demand), so that three conditions result:

$$R_S \leq S \text{ and } R_N \leq N, \text{ and } R_S + R_N \leq R_{dem}. \qquad (30)$$

Furthermore, treated waste and recycling should not exceed production waste and waste suitable for recycling (see equations (2) and (3)), respectively:

$$R_{wa} \leq W_Q \text{ and } R_{rec} \leq W_{rec}. \qquad (31)$$

This concludes the general structure of our regional economic-ecological model. In the next section results and conclusions of simulation experiments of a model which is a special case of our general model are presented.

5. Simulation of the Regional Economic-Ecological Model.

5.1. Regional Sustainable Development: Control variables, Scenarios and Indicators.

The general structure of this model has been analyzed by making assumptions about the specific functional forms of general relationships. Functional specifications and parameter values are given in appendix B. Parameters were given values such that the model generates realistic patterns[2]. So the resulting open system model does not describe an actual region or nation. However, it may provide an indication of possible development patterns for certain open economic-ecological systems (namely, those satisfying the underlying assumptions).

The following variables are controlled for the simulation experiment: investment, cross-boundary flows, environmental policy instruments, allocation of resource use, the perception of supply of resources and domestic-foreign price level ratio. The choice of these control variables reflects the capabilities of the model. However, this does not always mean that their real-world counterparts can be controlled as easily, not even the so-called policy variables.

The following scenarios can be studied with the present model and are useful for analyzing regional sustainable development in a regional system. Some scenarios are to be used for comparison with others, while others can be regarded as part of a comprehensive sustainable development scenario.

1. Reference scenarios, which include (a) stationary state of open system: no growth, i.e. no capital accumulation, and (b) strong growth in closed system: no inflows and outflows.
2. Growth scenarios, including (a) weak/normal growth: investment higher than capital depreciation, and (b) strong growth: investment high. The latter was taken in such a way as to cause a system collapse before the end of the simulation period. It may then serve as a reference for environmental beneficial strategies and policies under high growth.
3. Environmental policies involving the use of one or more of the following policies: waste treatment, research and development which generates techniques/capital with higher resource efficiency, recycling and environmental cleaning or replenishment.
4. Resource use scenarios, including the allocation of total extraction over the renewable and non-renewable stocks of resources. This may involve for example using fixed parts of the non-renewable and renewable resource, a constant amount from the renewable resource stock and the remaining amount needed from the non-renewable resource stock or the other way around, first extraction of renewable and then non-renewable stocks, and sustainable use of regenerative natural systems.
5. Feedback of resource scarcity to economic activity, by taking the supply of resources indicated by (a) the sum of all resource stocks and import of resources in the last period, or (b) the sum of the stock of non-renewable resources, the regeneration rate of renewable stocks, and the import

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[2] Initially, data on world level were used to set up a closed model, later this model was extended to include all cross-boundary flows.

of resources in the last period, or (c) the same sum as under (b), with the first part replaced by a fraction of it, to include intergenerational considerations.

6. Environmentally beneficial strategies, which may include (a) sustainable waste emission, (b) sustainable use of renewable resources and waste emission.

7. Scenarios dealing with the openness of the system, with regard to (a) economic openness, that may be include by allowing for changes in ratio of domestic to foreign price level, and (b) ecological openness in terms of flows of waste and pollution.

Some of these scenarios may represent not only a specific development but also a specific type of region, namely: goods importing/exporting, resource importing/exporting, or pollution importing/exporting.

The following indicators for RSD are used: (1) stock of non-renewable resources, (2) stock of renewable resources, (3) stock of pollution, (4) consumption per capita, (5) the ratio of total regional income to total regional production, (6) the stock of productive capital, (7) environmental quality, (8) regeneration rate, (9) assimilation rate, (10) net import of resources, (11) net import of goods, and (12) net import of emitted waste. To evaluate the total system behaviour in the context of sustainable development also intergenerational considerations should be included. That means that the dynamic pattern as a whole must be evaluated, either by looking at the trend, minimum values attained and fluctuation. The first should not decline, the second not be too low, and the third not be too intense.

5.2. Simulation Results and Evaluation.

Instead of studying all of the mentioned scenarios extensively only the following ones are discussed. The conclusions are based on results obtained by simulating[3] the model. Results for scenarios (iii) and (iv) (see below) can be found in the graphs 2 and 3(a-d)[4]. For each scenario the assumptions, the simulation results, and the conclusions in terms of RSD are discussed. For scenario 2 to 8 only the assumptions that are altered in comparison with scenario i are mentioned. Scenarios i and ii are included for reference (and i may be seen a one type of possible RSD scenario as well). Table 1 summarizes the conclusions in terms of RSD performance of variables.

i) Stationary state.

Assumptions: Investment equals depreciation; as long as no resource limits are being met renewable resource extraction will equal non-renewable resource extraction; the initial stock level

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[3] The time period of simulation is 50 years. The simulation model is developed in the (Apple software) package STELLA, as a set of interacting stock-flow processes. Solutions were obtained by approximation with Euler's method, using a time-step equal to the basic time unit in the model, which is in years.

[4] The a-versions of these graphs show the following variables: 1= the stock of renewable resources, 2= the stock of non-renewable resources, and 3= the stock of pollution. The b-versions show: 1= consumption per capita, 2= regional income divided by regional production, and 3= stock of productive capital. The c-versions show: 1= environmental quality, 2= the regeneration rate of renewable resources, 3= assimilation rate. The d-versions show: 1= net import of goods, 2= net import of resources, and 3= net import of emitted waste.

of renewable resources is its maximum level, which higher than the one at which the regeneration rate is optimal, so that a decrease in the stock level will initially lead to an increase in the regeneration rate (see 4.4); no environmental policy outlays; the initial level of the pollution stock is positive, while it (together with the renewable resource stock level) implies an optimal environmental quality; perception of resource availability equals sum of stocks of resources and resource import of the last period; open system, i.e., import and export of goods, resources, emitted waste, and outflow of pollution.

Simulation results: The stock of renewable resources decreases initially until it reaches a level at which the regeneration rate can support the demand for renewable resources; the stock of non-renewable resources slowly decreases and is exhausted before the end of the time-horizon; to compensate for the loss of non-renewable resources after its exhaustion the extraction rate of the renewable resource is increased which leads to a slight decrease in its stock level and increase in its regeneration rate; the stock of pollution is constant as a result of equality between total net waste emission less net pollution outflow less assimilation; the stock of capital and the consumption per capita are constant over the whole period; environmental quality is constant over the whole period as is the assimilation rate, while the regeneration rate increases initially, stabilizes and finally increases again; import equals export for goods and resources; net import of emitted waste is slightly increasing and reaches a constant very low positive level.

Conclusions: The trends for the main variables are constant levels over time, no fluctuations for any variable; if the level of consumption per capita is sufficient the regional system as described by our model (for the chosen set of parameter and initial stock values) will follow an RSD path if economic growth is absent.

ii) Closed system with growth

Assumptions: Investment much higher than depreciation; its level is chosen so as to cause finally a destruction of the system when no environmental control in whatever way is included; no imports and exports of goods, resources, emitted waste and pollution.

Simulation results: Investment gives a high incentive to the accumulation of productive capital and high growth in output, which on its turn causes a rapid decline of the stock level of non-renewable resources and a rapid increase in the stock of pollution; the consequences are a decreasing environmental quality and exhaustion of the non-renewable resource stock, which together cause the stock of renewable resources to decline rapidly; as this decline is set in motion, fluctuating patterns are shown that result from the reaction of decreasing production to increasing resource scarcity; as a reaction to increasing resource scarcity the production growth is tempered, which leads to a levelling off in the stock of pollution; however, the downward trend in environmental quality cannot be stopped in time so that finally also the renewable resource stock is exhausted; for consumption per capita these patterns imply a strong increase initially, followed by a levelling off, and finally a decline to zero; environmental quality reaches its minimum level.

Conclusions: The time pattern of the renewable resource stock is a downward trend to zero[5],

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[5] A scenario with the same assumptions except for a level of the renewable resource stock that is related to a higher regeneration rate the time pattern shows an increase initially followed by a rapid decline to zero thereafter.

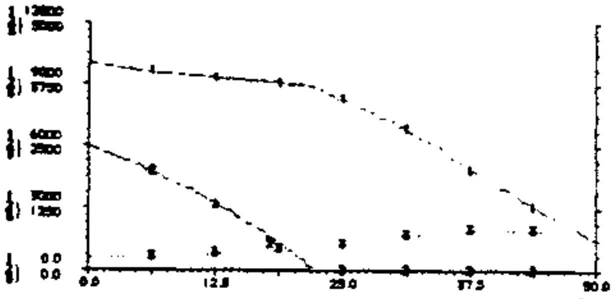

Figure 2a Open system with growth

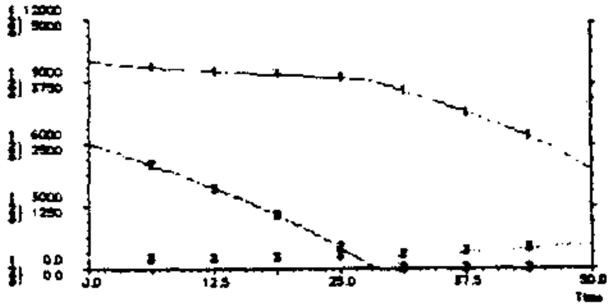

Figure 3a Environmental policy all

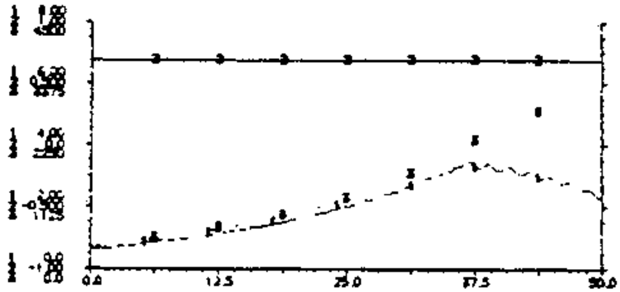

Figure 2b Open system with growth.

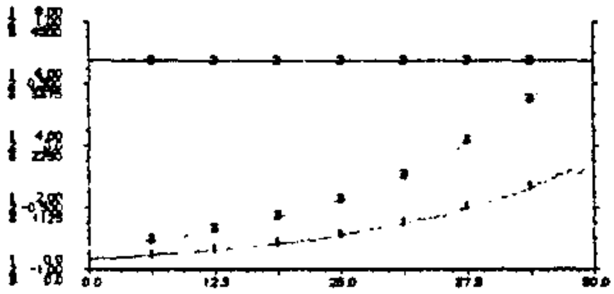

Figure 3b Environmental policy all

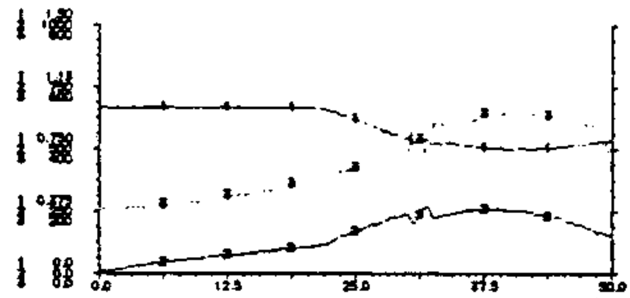

Figure 2c Open system with growth

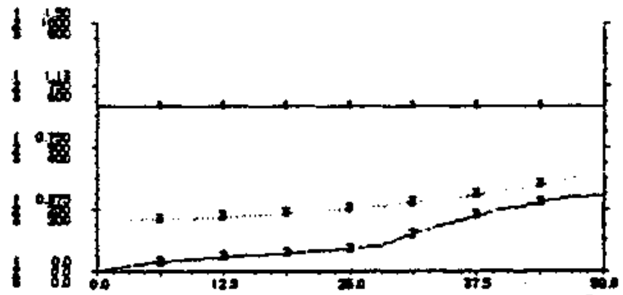

Figure 3c Environmental policy all

Figure 2d Open system with growth

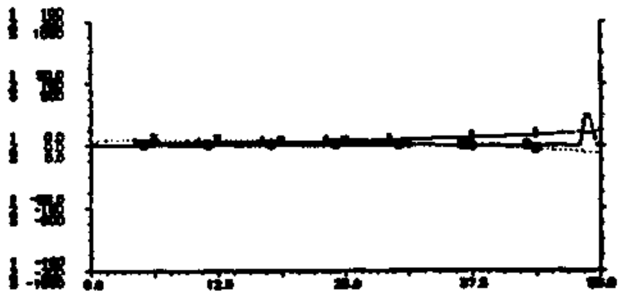

Figure 3d Environmental plicy all.

while that of the consumption per capita shows an increase initially followed by a rapid decline to zero thereafter; clearly, such a path is not an RSD path.

iii) Open system with growth

Assumptions: The assumptions of scenario i except for investment, which is assumed as in scenario ii.

Simulation results: The stock of productive capital accumulates rapidly, which causes a rapid decline in the non-renewable resource stock and a slow decline in the renewable resource stock; the pollution stock increases; at the point of exhaustion of non-renewable resource its stock starts to decrease more rapidly; after some time increasing resource scarcity and decreasing environmental quality cause production to be slowed down; the consumption per capita then starts to follow a downward trend with fluctuations arising from the reaction to resource scarcity; at the same time, more resources are imported and more waste is exported, together causing the stock of pollution and environmental to stabilize at a constant positive and non-optimal level, respectively; the renewable resource stock follows a downward trend and is still positive (but small) at the end of the period; the regeneration rate has reached its maximum and is also decreasing.

Conclusions: The time paths for the renewable resource stock and the consumption per capita are in the final part of the time period following a declining trend; at the same time there is net resource import and net waste export; so this path is surely not an RSD path.

iv) Environmental policy all

Assumptions: As in scenario iii, but now with a positive level of environmental policy outlays, and an equal use of environmental policy instruments; these include waste treatment, research and development for a higher resource efficiency of production, recycling of waste materials, and environmental cleaning directly affecting environmental quality.

Simulation results: We mention here the results as compared to and the main differences with the results under scenario iii; consumption per capita does not decline at a certain stage but keeps on rising; the increase in pollution is slowed down; there is now less net resource import and less net waste export; the time of exhaustion of the non-renewable resource stock is postponed; environmental quality is kept at an optimal level; the last part of the time path of the renewable resource stock is a downward trend, while at the same time the regeneration and assimilation rates are increasing slowly.

Conclusions: A stronger resource saving policy may be desirable in order to turn the downward trend of the stock of renewable resources; this may imply a shift in the use of one to another policy instrument; so still no RSD path is obtained; a very high level of environmental outlays may generate a stable level for both the renewable resource stock and the consumption per capita, however, the level of the latter may not be sufficient to label such a development as an RSD.

v) Research and development

Assumptions: As in scenario iii. All environmental policy outlays - equal to those in scenario iv - are spent on research and development for a higher resource efficiency of production.

Simulation results: Compared with scenario iv the results are worse; the reason is that environmental quality is declining which negatively impacts on regeneration and assimilation; this causes the stock of renewable resources to decrease more rapidly and the income per capita to decrease slightly; again more resources import and waste export is the result.

Conclusions: This scenario is less desirable then scenario iv, as the performance of every indicator is worse.

vi) Sustainable use

Assumptions: As in scenario iii except for the resource strategy, resource scarcity perception, and the initial level of the stock of renewable resources; here the extraction rate of renewable resources is not higher than the regeneration rate, at every point in time; perception of resource availability equals sum of the regeneration rate, the stock of non-renewable resources, and resource import of the last period; the initial stock level of renewable resources is in between the maximal level and the level at which the regeneration rate is optimal (this is done to assure a positive regeneration rate).

Simulation results: Initially no non-renewable resources are used; when economic production has increased to a certain level, the stock of non-renewable resources decreases, while the renewable resource stock is maintained at the same level; the perception of resource scarcity and the actual level of resources first causes fluctuating reactions of production and income per capita the levels of which drop thereafter; this allows for an increase in the renewable resource stock, and an associated decrease in the regeneration rate, so that resource scarcity increases as long as the strategy of sustainable use is maintained; finally, the economic system breaks down, while the ecological system is maintained; the environmental quality is non-optimal at the stage in which the level of economic activity is high, but afterwards becomes optimal again as a result of a declining stock of pollution.

Conclusions: The reaction mechanism of production to resource scarcity and the maintenance of the sustainable use strategy cause the economic system to collapse; if a temporary higher than sustainable use of renewable resources is allowed for these conclusions are changed toward more optimistic ones for the economic system.

vii) Intergenerational concern

Assumptions: As in scenario vi, except for the perception of resource scarcity; this is now represented by the sum of the regeneration rate, 1% of the stock of non-renewable resources and the import of resources; the underlying idea is that the non-renewable resource stock should be available for the next hundred years.

Simulation results: We compare the results with scenario vi; this time the non-renewable resources are not exhausted, but instead the renewable resource stock is declining; income per capita again drops when resource scarcity increases and environmental quality has decreased; pollution then stabilizes.

Conclusions: Finally, both the renewable resource stock and regeneration rate are declining, so that the prospective is not positive; now, the economic system has not collapsed, but the ecological system may be heading to a collapse.

		scenarios						
		i	ii	iii	iv	v	vi	vii
RSD evaluation criteria based on levels and the direction of time paths at the end of the period	consumption per capita	0	-	0	+	0	-	0
	environmental quality	+	-	0	+	0	+	0
	stock of renewable resources	+	-	-	-	-	+	-
	import of resources	+	X	-	0	-	+	0
	export of waste and pollution	+	X	-	0	-	+	-
	fluctuating patterns	+	0	-	0	0	+	+
General performance in terms of RSD		+	-	-	-	-	-	-

TABLE 1: RSD-performance of scenarios (i) to (vii).
'+', '-' and '0' denote 'good', 'bad' and 'moderate' performance. 'X' means 'not relevant'.

In Table 1 the performance of each scenario in terms of RSD is derived on the basis of 6 criteria. Both the level and the direction are considered for each of the variables mentioned. If, for instance, the general level of the time path of the criterion-variable is high, and the time path has a slight tendency downward at the end of the period, then the evaluation is 'moderate'. A rapid decrease at the end of the period is labelled as a 'bad' performance. 'Good' performance includes a sufficient level and a non-downward tendency towards the end of the period. Finally, the general performance is negative when at least one specific performance is negative, and positive when some are positive and all are non-negative.

6. Conclusions.

Analysis of regional sustainable development must be based on various general considerations: (1) intergenerational distribution of regional consumption, (2) regional environmental quality, (4) resource strategies, (5) waste strategies, (6) cross-boundary flows of goods, resources, waste and pollution, (8) physical and ethical/behavioral feedback from ecology to economicy, and (7) sustainable development outside the region. Models that are useful for a general analysis of RSD should satisfy certain requirements. Based on these, a general model was developed which can be used to study: growth in an open system, environmental policies, various resource and waste strategies, ethics and future generations, and openness.

Some conclusions from the simulation experiments with this model are that small variations in the level of the stocks is not crucial for the general dynamic characteristics of the time paths generated except for the level of the stock of renewable resources that is chosen. A closed system shows more drastic changes after exhaustion or collapse of resource stocks than an open system. The latter can be supported from outside, however, whether such a development can be sustained depends on extra-regional sustainable development. This must be studied in a multiregional framework. Changes in the level of the stock of renewable resources are generated by an interweaved pattern of changes in resource strategies, extraction rates of non-renewable resources, compensation by import of resources, export of resources, and environmental quality. The regenerative natural sytem may collapse when extraction rates are too high, the stock of pollution is too high, or by a synergetic effect of both.

Further research regarding the general behaviour of the proposed model will lead to the generation of complicated models. However, in order to study ecologically sustainable economic development in a logical, controllable framework, this seems an inevitable direction of research. Simple models will only give partial views and we prefer to experiment with complicated models rather than with reality.

Appendix A: Model Notation.

Stock variables:

K = productive capital
Pop = population level
T_{rd} = cumulative R&D outlays
S_{wa} = waste treated
N = renewable resources
S = non-renewable resources
P = pollution

Flow variables:

Bc = current account balance
Bk = capital account balance
C = total consumption
C_m = imported commodities for consumption
C_Q = consumption from produced goods
C_R = consumption from resources
I = investment in productive capital
I_m = inflow of capital investment
I_x = outflow of capital investment
O = other material outlays
O_m = subsidies from supraregional institution
O_{rdm} = indicator for extraregional/exogenous technical progress
O_a = outlays for waste treatment
O_{rec} = outlays for recycling
O_c = outlays for environmental cleaning
O_{rd} = outlays for R&D
Q = output from production
Q_m = imports of output from production
Q_x = exports of output from production
Q_{tot} = total regional income
E = ecological quality indicator
P_{rel} = domestic price level relative to foreign price level
P_x = export of pollution from the stock of pollution
R_{dem} = total productive and consumptive demand for resources
R_{sup} = total extraction/supply of renewable and non-renewable resources
R_{short} = denotes whether resource supply equals demand
R_m = imported resources
R_x = exported resources
R_N = renewable resource extraction
R_S = non-renewable resource extraction
R_Q = total resource input for production
R_{Qn} = production demand for newly extracted resources
R_{rec} = recycled resource material input for production
W = gross waste (before waste treatment and recycling)
W_Q = gross waste from production
W_{rec} = waste amenable for recycling
R_{wa} = waste treated
W_{em} = emitted waste
$W_{em,m}$ = import of emitted material waste

$W_{em,x}$ = export of emitted material waste from the flow of waste
W_{ra} = waste treated and recycled
W_{sust} = indicator for feedback from pollution to economic activity

Functions:

c = ratio of resource input to material output in production
f_{RC} = relates level of consumption of resources to that of produced goods consumption per capita
e = determines resource shortage
F = production
f_a = waste treatment
f_r = recycling
f_{Qm} = import of goods and services
f_{Qx} = export of goods and services
f_{Rm} = resource import
f_{Rx} = resource export
D = depreciation of capital
H = environmental quality function
G = regeneration function of renewable resource capacity
M = assimilation function

Parameters:

T = time horizon
N_{min} = critical resource level for growth function G
N_{max} = upper bound level of renewable resource capacity (carrying capacity)
c_{rec} = fraction of W_{ra} that is recycled
$c_{em,x}$ = fraction of total regional waste emission that is exported
m = safety margin for pollution-economy feedback
r = safety margin for resource-economy feedback
initial stock levels K_0,Pop_0,N_0,S_0,P_0

Appendix B: Specification and Parameter Values of the Simulation Model.

Initial values of the stock variables man-made capital, renewable resources, non-renewable resources and pollution are such that there ratios are realistic, so that the materials balance conditions can be included. The stock variables population and cumulative R&D outlays should not be materially consistent with the other stocks as this is not relevant for the material balance principle. $K(0)=500$, $S(0)=4000$, $N(0)=5000$, $P(0)=100$, $S_{wa}=0$, $T_{rd}(0)=100$, $Pop(0)=100$.

We have assumed that population has stabilized in order to leave population issues for the moment out. The part of total consumption that is directly obtained from the natural resource stock (C_R) is taken as being a constant fraction (0.2) of produced consumption. Consumption, investment and environmental policy outlays are a constant fraction of regional income and differ between scenarios (e.g., investment high (low) fraction of income for 'high-(low-)growth scenario'. Depreciation of capital (D) is based on an average economic life-time of man-made capital of 40 years so that a rate of 0.025 time the capital stock is chosen.

Environmental quality (E) is determined in the following way:

$$E = \max\{\underline{E};\mathrm{MIN}\{E_{max},(N/N_{crit})*(P_{crit}/(a+P)*((b*(O_c+c)/(O_c+b))\}\}$$

$\underline{E}=0.2$, $E_{max}=1$, $a=500$, $b=1.5$, $c=1$. N_{crit} is chosen as a weighted average of the carrying capacity K_N and N_{opt} (value of N for which regeneration function G(N) (see below) is maximal, $N_{opt}=K_N/2$); we assume that $N_{crit}=(N_{opt}+K_N)/2$. P_{crit} is chosen as $10*P(o)$.

For the regeneration rate of renewable natural resources (G) we have assumed a logistic growth curve with intrinsic growth r_N and carrying capacity K_N. Furthermore, for environmental quality (E) below a critical level $E_{crit}=.5*Emax$, these parameters have constant values a and b, respectively; for E above E_{crit}, both have values decreasing in E: $r_N=a*(E)**c$ and $K_N=b*(E)**d$. We assume that the *initial stock level* (N(0)) *is optimal* (i.e., G(N(0)) *is the maximal value that* G( ) *can attain*); from this (and the assumption of logistic growth) it follows that $K_N=2*N(0)$; r_N is determined by solving the equation $G(N(0))=r_N*K_N/4$, which gives $r_N=2*G(N(0))/N(0)$. We assume that $a=b=1$ and $c=d=0.5$.

The assimilation rate of pollution (M) is assumed to be affected by the level of environmental quality below the critical level E_{crit}. A general formulation is a decrease rate times the present stock, or: a(P)*P with the rate a( ) decreasing in the level of the stock of pollution P; the motivation for the latter is that with a higher stock of pollution the assimilative capacity decreases; a specific choice for a( ) may give rise to a general specification a*(P**b) ($0<b<1$). For E below Ecrit a(P) is replaced by $b(E)=(E/E_{crit})**d$. Ecrit is as above, $a=c=1$, $b=0.5$, $d=0.5$.

The following production function is used: IF $E<E_{crit}$

THEN $Q = \mathrm{MIN}[R_{sup}/c(T_{rd}),(1+d*W_{sust}*R_{short}*((E+b)/(E_{crit}+b))k*K]$

ELSE $Q = \mathrm{MIN}[R_{sup}/c(T_{rd}),(1+d*W_{sust}*R_{short}*k*K]$.

d is a dummy variable, which is 1 for scenarios where pollution-economy feedbacks are included and 0 in other cases. Ecrit=0.5 and we assume that at most (for E_1=0) x% of production is damaged (e.g., crops in agriculture) or lost, then $(100-x)/100=b/(E_{crit}+b)$ or $b=((100-x)/x)*E_{crit}$; we assume $x=20$ so that $b=4*E_{crit}$. We assume $k=0.25$.

Total resource demand of production (R_Q) equals $a*(T_{rd}+b)/T_{rd}$, where we choose $a=1.2$ adn $b=50$. Recycled amount of waste (Rrec) is - based on the fact that the upper bound to recycling is the amount of waste W_r that goes into the recycling process - represented by $R_{rec} = u*O_{rec}/(O_{rec}+a)*W_r$, where the value of a is dependent on the units of measurement of O_{rec} and the effectiveness of initial outlays on recycling. In view of data for recycling of several types of resources we assume the following: $u=0.7$ (optimistic) and $a=8$. The amount of abated waste from production (R_{wa}) is smaller or equal than the total waste flow from production W_Q; outlays for abatement activity result in an abated waste amount in the following way: Rwa = u*Oa/(Oa+a)*WQ. Assuming a maximum abatement of 90 %, $u=0.9$. We assume $a=4.8$.

The functional specifications mentioned in the main text for $f_{short}(\ )$ and $f_{wsust}(\ )$ are used with values for parameters r and m variable ($0.1 \leq r, m \leq 1$) for different scenarios.

References.

Archibugi, F. and P. Nijkamp (eds) (1989), Economy and ecology: towards sustainable development, Kluwer Nijhoff, Dordrecht

Ayres, R.U. (1978), Resources, environment, and economics: Applications of the materials/energy balance principle, Wiley-Interscience, New York

Barbier, E.B. (1990), "Alternative approaches to economic-environmental interactions", Ecological Economics 2, 7-26

Bergh, J.C.J.M van den, and F. Soeteman (1990), "Sustainable development of global and regional systems", SPIDER working paper 2, Faculty of Economics/Institute for Environmental Studies, Free University, Amsterdam

Clark, C.W. (1985), Bioeconomic Modelling and Fisheries Management, Wiley-Interscience, New York

Miernyk, W.H. (1982), Regional analysis and regional policy, Oelgeschlager, Gunn and Hain, Cambridge Massachusetts

Odum, H.T. (1987), "Models for national, international, and global systems policy", in: L.C. Braat and W.F.J. van Lierop (eds.), Economic-ecological modeling, North-Holland

Opschoor, J.B. (1987), Duurzaamheid en verandering, Inaugural Address, Free University, Amsterdam (in Dutch)

Turnovsky, S.J. (1977), Macroeconomic analysis and stabilization policies, Cambridge University Press, Melbourne

Walters, C.J. (1986), Adaptive Management of Renewable Resources, Macmillan

Wan, H.Y. Jr (1971), Economic growth, Harcourt Brace Javanovich, New York

Watt, K.E.F. (1968), Ecology and Resource Management: A Quantitative Approach, McGraw-Hill, NY

The World Commission on Environment and Development (WCED) (1987), Our Common Future, Oxford University Press

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