Assessing Sustainability: Some Conceptual and Empirical Challenges

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Abstract

In this paper we address two related conceptual and practical challenges in assessing "sustainability." The first is the criteria to be used, in particular the relationship between sustainability and measures of economic well-being and the use of monetary versus nonmonetary indicators. The second is the problem of determining which physical scales to use for sustainability assessments when there are multiple and overlapping "communities" or stakeholder groups. While neither set of challenges admits a definitive solution, there has been progress on the first set of issues – in particular, through the development of multi-criteria assessment strategies and stakeholder involvement processes. In contrast, the problem of how to assess sustainability in practice at multiple scales remains less well understood.

Keywords: sustainable development, integrated assessment, environmental indicators

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ASSESSING SUSTAINABILITY: SOME CONCEPTUAL AND EMPIRICAL CHALLENGES

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INTRODUCTION

While there continues to be substantial debate about precisely what "sustainability" entails, there is broad agreement that it involves not just the conditions in the economy, but also the underlying ecological and environmental systems in which economic activity is embedded, and the larger social system of which the economy is a part (PCSD 1996, Norton and Toman 1997). However, this relatively broad understanding of the concept leaves open many interrelated questions related to the measurement and assessment of sustainability.

A well-known element of this debate is the relationship between sustainability and measures of economic well-being. A number of authors have argued that conventional measures of economic welfare or surplus do not seem to adequately capture important dimensions of sustainability, such as social equity or other values that are difficult to express in monetary terms (see for example Toman, Pezzey, and Krautkraemer 1995, Howarth 1996). This line of reasoning has led many participants in the debate to favor multi-criteria approaches to sustainability assessment. The question then becomes, which values, and whose values, are incorporated in the assessment?

A related element is the question of monetary versus nonmonetary indicators. In attempting to assess sustainability, some countries (for example, Germany and the Netherlands) have incorporated some degree of environmental and economic interaction in their national accounts. Though a number of initial efforts were based on monetary measures, most efforts have abandoned these attempts in favor of physical flows, building on the work by Leontief (1936), Cumberland (1966), Daly (1968), Isard (1969), Ayres and Kneese (1969), and Victor (1972). The rationale for this appears to be the difficulty associated with monetary valuation of natural resources and residuals.

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Another, somewhat less familiar element of the debate over sustainability assessment is related to the physical or spatial scale over which sustainability is assessed. Many decisions that affect long-term economic, environmental, and social functions at larger scales (the region or nation) are made at a lower level (the community). Conversely, broader-level sustainability depends on the combined effects of a large number of smaller-scale decisions, and these decisions are not independent since there are effects that spill across socioeconomic and environmental boundaries (e.g., pollution of air or watersheds, regional economic growth promoted by local investments, mobility of people within larger urban areas). Yet, most indicators of sustainability that have been proposed and estimated are concerned only with larger geographical units (like nations).

In this paper we briefly explore each of these dimensions of sustainability assessment, with an eye toward practical dilemmas as well as theoretical constructs. We find the first issue more tractable than the second. In particular, regarding the definition of social criteria for sustainability, we argue that the concept of a multi-criteria framework is becoming widely accepted even among conventionally minded economists; the debate instead is on how different kinds of public values register in the analysis. Regarding monetary and nonmonetary indicators of sustainability, we note that in addition to a number of useful monetary measures, nonmonetary measures of ecological resource importance can be structured in a way that is useful for setting relative rankings of different resource services and establishing policy priorities. With these approaches, indicators that shed light on sustainability at different spatial scales can be constructed. However, determining how to integrate across different scales in assessing sustainability remains a challenge. We identify some of the dimensions of the problem, but a solution must await further research and experience.

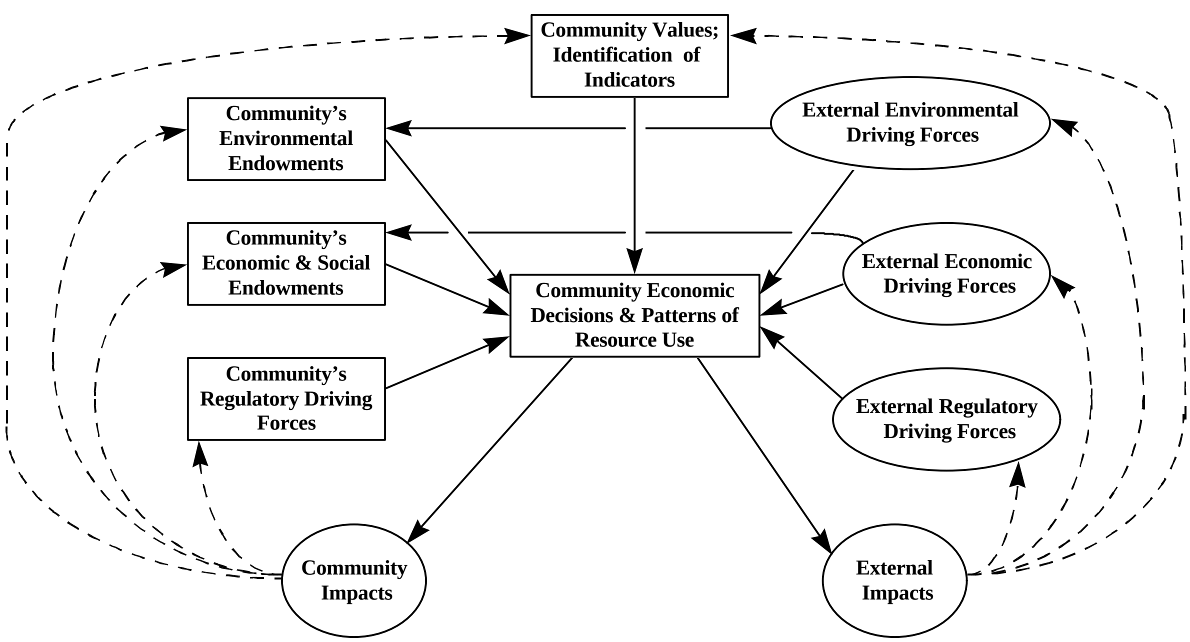
CONCEPTUAL FRAMEWORK

The "pressure-state-response" framework (OECD 1991) provides a useful way of organizing information about the elements of sustainability. According to this framework, the condition of society can be seen as depending on a number of *states* -- for example, the quantity of built capital, the size and quality of natural resource stocks, the state of knowledge, the quality of the environment, the health of environmental systems, the health of its members, and the performance of social institutions in meeting and coordinating human needs. From an economic perspective these states can be thought of as capital stocks, though the use of this terminology is broader than standard uses in economic theory and there is no necessary presumption that all relevant values can be monetized easily (or maybe at all). However, researchers have not been able to estimate the monetized economic value of natural capital. It is thus useful to consider other indicators, in addition to more conventional (absolute) measures of economic value, to compare natural capital usage and evaluate its effects.

Human activities produce *pressures* on various states -- some potentially detrimental, like releases of pollutants; some ameliorative or positive, like investment in environmental restoration and human capital; and some more neutral or ambiguous, like depletion of natural resource stocks (not inherently detrimental, depending on the pace of depletion and the nature of other -- possibly compensating -- activities). These pressures in turn cause *responses* in the states (environmental degradation or improvement, enhanced productivity). This framework draws attention to the assessment of a variety of *changes in stocks* and other *flows* that affect a society's well-being. One would be concerned, for example, not only with the level of current activity but also with the level and composition of economic investment, as well as with investment in education (human capital formation). Environmentally, one would be concerned with changes in the quantity and quality of available natural resources as well as with changes in environmental quality and the functioning of ecosystems that provide important amenities and services.

Figure 1 captures the general framework on which this paper builds. We begin with the basic idea that a "community" is concerned with its current and future economic, environmental, and social well-being. A community here is taken to be any organized social unit with some coherent rules of governance that is contained in some larger economic, environmental, and social systems. It is natural to think of community as a city or small region within a larger country, though for global transboundary problems we might think of the community in question as a nation within the international system.

Figure 1. Conceptual Framework



As seen in Figure 1, there are two distinct types of interactions represented by solid and dashed lines. The solid lines depict the interactions among community values (and the indicators that help shape those values), community endowments, external driving forces, community economic and resource use decisions, and community and external impacts. The figure suggests that external environmental, economic and regulatory forces have a direct affect on a community's economic and resource use decisions, a community's environmental endowments and its economic and social endowments. Furthermore, the community's values, environmental endowments, economic and social endowments, and community's regulatory driving forces influence the community's economic and resource use decisions. The dashed lines depict the resulting feedback from the community's economic and resource use decisions. Once the community decisions have affected the community itself and the world outside it, the impacts feedback into the community's future economic and resource use decisions.

We can formalize some of the relationships depicted in Figure 1 with a simple extension of the extended input-output accounting framework pioneered by Ayres and Kneese (1969) and further developed by Duchin (1996) and others including Victor (1972), James (1985), Forsund (1985), Miller and Blair (1985), Pearson (1989), and Smith (1995) (see also Faber and Proops 1993 for a more complex system). In this framework, economic activities and resources and environmental effects within a particular community are distinguished from those outside the community. The former are denoted by the subscript *H*, while the latter are denoted by the subscript *F*. Since the community and its surrounding area are economically and environmentally interdependent, flows arising within *H* affect *F* and vice versa. This model does not explicitly keep track of employment or human capital, though the framework could easily be extended to do so.

To account for the flows of intermediate and final goods, let $x = (x_H, x_F)$ denote the vector of net economic outputs, where each subvector represents outputs inside and outside *H* respectively. Following standard convention, let a_{ij} denote the input of the ith commodity per unit output of the jth good. For any $i \in H$, let A_{iH} denote the sum of the $a_{ij}x_j$ over all $j \in H$, and let A_{iF} denote the analogous sum over all $j \in F$. Then A_{iH} and A_{iF} are the total net "domestic" and "foreign" input demands.

Production also depends on the utilization of the services of built capital stocks. Let $K = (K_H, K_F)$ denote capital stocks inside and outside the community (the partition of this vector need not bear any relationship to the partitioning of *x* above). Since capital services are assumed not to be mobile, for $i, j \in H$, b_{ij} is defined as the input of the ith type of capital per unit output of the jth good in the community. Summing $b_{ij}x_j$ over *j* for each *i*, the total demand for the services of the ith domestic capital good, denoted B_i, can be obtained. A similar construction yields demands outside the community for their types of capital goods. The vector $B = (B_H, B_F)$ is the vector of total demands for capital services, assumed to be satisfied by existing capital stocks (i.e., this simple framework does not address absolute constraints on economic outputs due to capital constraints).

Commodities included in the *x* vector can be used to augment capital stocks as well as intermediate and final goods. Let I_j denote the gross investment in capital stock type *j*, and let $I = (I_H, I_F)$ denote the vector of all investments. Let a_{ijK} denote the input of the ith commodity per unit of gross investment of type *j*. Then the sum of the $a_{ijK}I_j$ over all *j* yields A_{iK}, the total input of commodity type *i* for the augmentation of capital. A_{iK} can be partitioned into demands within and outside the community for inputs to capital formation. For $i \in H$, the component A_{iKH} represents the demand within the community for inputs of i to be used in capital formation. For $i \in F$, the component A_{iKF} represents the demand outside the community for inputs of i to be used in capital formation. This framework does not consider the direct importation of capital inputs, as opposed to purchased inputs outside the community for capital fabrication in the community. However, it can be extended to take into account comparative advantage outside the community for producing capital goods as well as intermediate and final goods. As a result, net changes in built capital can now be represented. Specifically, assume that capital depreciation is related to the rate of use of capital services. Then, $\delta(B) = (\delta_H(B_H), \delta_F(B_F))$ can represent this relationship, and net changes in capital inside and outside the community are $(\Delta K_H, \Delta K_F) = (I_H - \delta_H(B_H), I_F - \delta_F(B_F))$.

Now consider natural resource stocks and sinks. Let $S = (S_H, S_F)$ denote the vector of primary resource stocks (energy, minerals, fish, etc.). Let c_{ij} denote the input of the ith resource per unit output of x_j. Then summing $c_{ij}x_j$ over j, domestic and foreign demands for the community's resources, and the community's demands for foreign resources can be calculated. Domestic and foreign demands are denoted by C_{iH} and C_{iF} respectively. Produced inputs must be used for resource extraction and processing, as well as for capital goods and meeting final demands. Let a_{ijS} denote the input of x_i per unit extraction of resource type S_j. Then summing $a_{ijS}C_j$ over j, the total use of produced goods in the natural resources sector, denoted A_{iS}, can be calculated. However, since unit input requirements for extraction of many natural resources can be assumed to rise as resources are depleted, the coefficients a_{ijS} generally will be decreasing functions of S_j (see, e.g., Bohi and Toman 1984 and Clark 1990).

For resources that are nonrenewable, stock change is simply $\Delta S_j = -C_j$. Renewable resources, however, will grow over time at a rate that generally depends on the in situ stock. Thus, for these resources the net stock change can be represented by $\Delta S_j = -C_j + \varphi_j(S_j)$, where the second term represents the natural regeneration function. (The model also could be extended to incorporate substitutes for natural regeneration like aquaculture.) Note that this entire framework emphasizes the size of in situ stocks and their relationship to extraction costs (especially for nonrenewable resources) and stock regeneration (for renewable resources). This perspective is very different from one based on such accounting conventions as "proved reserves" of oil and gas. In addition, the representation of the growth equation for renewals could be extended to depend on environmental residuals, to which we turn next.

The penultimate step in the development of this framework is an accounting of the effects of production, investment, and resource use on the natural environment. Let $R = (R_H, R_F)$ denote a vector of environmental residuals (pollution production, reduction of species population) inside and outside the community respectively. These residuals are related to economic activities through coefficients d_{ij}, d_{ijK}, and d_{ijS} that relate creation of residual i to unit increases in x_j, I_j, and C_j respectively. Summing over j, the magnitudes of the residuals generated are now calculated. Note that these summations run over $j \in H$ and

$j \in F$, indicating local residuals could result in part from economic activity outside the community, while residuals outside the community can be affected by activity within it.

Given the residuals, changes in the environmental components of "natural capital" can now, in principle, be determined. Let $Z = (Z_H, Z_F, Z_G)$ denote a vector of environmental state variables, in which local environmental states in the community are distinguished from states outside the community and "global" states that transcend the boundaries separating the community from the world surrounding it. For example, components of Z_H or Z_F could represent local air quality, while components of Z_G represent regional water quality, biodiversity or global climate change. Changes in these environmental states are assumed to be related to the generation of residuals, so that $\Delta Z_H = \psi_H(R_H)$, $\Delta Z_F = \psi_F(Z_F)$, and $\Delta Z_G = \psi_G(R_H, R_F)$. This simple model does not include damage remediation. However, the model could be extended to include other sectors that make claims on produced and natural resources (and generate their own, presumably less harmful, residuals) in order to ameliorate the damaging effects of economic activities.

To summarize, the framework so far developed here allows, in principle, the ability to calculate the following:

- total net outputs of produced goods within the community $(A_i + A_{iK} + A_{iS})$, for consumption, intermediate production, capital formation, and resource extraction, both within the community and outside it;

- total imports of produced commodities and natural resources (and, by extension, capital goods);

- total income generated in the community (including, in an extended version of the framework, net transfer payments received from outside it as well as consumption of publicly provided goods);

- net changes in the community's produced capital stocks (ΔK_H), as well as capital stock changes in the larger economic system;

- net depletion (or renewal) of the community's natural resource stocks (ΔS_H), as well as changes in resource stocks in the larger system;

- flows of environmental residuals (ΔR) inside and outside the community, and their interdependent effects on environmental quality and ecological function (ΔZ) within the community, outside it, and globally.

Specific examples of questions that one could in principle address with this framework include: To what extent can local resource depletion be offset by imports of resources from elsewhere? How large are net changes in different capital components within the community, and to the extent these are monetizable, what is the aggregate level of saving or dissaving? How is environmental quality and ecological function being affected by local damages stemming from activities outside the community; and to what extent is the community itself possibly "exporting unsustainability" by its own contributions to cross-boundary resource depletion or damage?

Two broad and related areas of difficulty handicap the empirical implementation of the sustainability assessment framework sketched above. One is the lack of capacity to carry out regional input-output modeling with cognizance of the roles played by natural resources and the environment. The other is a comparable lack of capacity in regional environmental-economics modeling. Beyond these specific problems, there are several other limitations related to both the theoretical basis of input-output models and associated measurement problems (see Coughlin and Mandelbaum 1991 for details). The most important of these problems is the assumption of a fixed technological menu. This is in fact a fairly serious weakness since one of the essential questions underlying sustainability is the capacity of substitution (including the substitution of knowledge for other resources) to ameliorate resource scarcity or damage.

Beyond these more technical concerns, there is a more fundamental problem of incompleteness in the framework sketched above. If one did evaluate all the net stock changes and other flows just enumerated, what would one make of this information? The framework as developed has no criteria for evaluating alternative "states of the world," from the perspective of the community or the larger system. We must then first consider how such criteria might be established.

DEFINING SUSTAINABILITY INDICATORS IN PRINCIPLE

As already noted, there is a large and growing literature on the strengths and weaknesses of different criteria for assessing sustainability. The conventional economic approach of applied cost-benefit analysis would take the stock changes and other flows generated by the accounting framework sketched above and evaluate the aggregate net change in all flows using shadow prices that reflect the marginal utilities of the changes. Typically the shadow prices in this framework are taken to be market prices or market prices corrected for various market externalities (Dasgupta and Mäler 1991). Future values would be discounted to reflect some measure of the social rate of time preference.

Because of concerns about the capability of this framework to fully or adequately address sustainability issues, a number of authors have proposed alternative intergenerational social welfare functions that put more emphasis on intergenerational allocation issues (see Toman, Pezzey, and Krautkraemer 1995 for a review). Among the many criteria considered in these studies are nondeclining utility, nondeclining consumption, and nondeclining value of total investment in the manufactured, human, and natural capital stocks (the familiar "weak sustainability" criterion of Pearce and Atkinson 1993). An important theoretical drawback of these approaches is that they are imposed from outside the socioeconomic system, with no assurance that they are compatible with the values and incentives of the stakeholders in question.

A practical problem is that these measures may be misleading as to the sustainability or unsustainability of an economy if they are calculated using market prices that reflect unsustainable behavior (Asheim 1994, Pezzey 1994).

Still another approach ("strong sustainability") would attach particular importance to changes in the magnitudes of certain stocks (e.g., "critical" stocks of natural capital). This perspective responds in part to the concern that the welfare of future generations is being compromised by depletion or degradation of "irreplaceable" capital, i.e., stocks which admit no ready substitute. Under this approach, environmental or broader sustainability criteria are established a priori (e.g., "critical load" limits on SO2 emissions and threshold concentrations of atmospheric CO2), and policy takes these targets as given while seeking the most effective and least costly ways to achieve the goals. However, there is no assurance that this approach is compatible with the values and preferences of the affected population either. The assumption of sharp thresholds in socioeconomic risks from nonsubstitutability also can be problematic, especially at local scales.

There is a growing conviction that a multi-criteria approach is appropriate for assessing sustainability (or, for that matter, a number of other values). While some analysts see certain values as inherently incommensurable (e.g., Munda 1996), others take a more pragmatic view about the need to supplement measures of economic net benefits with information about distributional consequences and environmental consequences that are difficult to monetize (Kopp, Krupnick, and Toman 1997). But given that a multi-criteria approach is to be pursued, how are the requisite values to be identified?

There are dangers to having these values specified by an intellectual elite whose concerns may not reflect those of the larger community. There is also a danger of simply having values be projected by a population without much familiarity with the issue at hand. We therefore advocate an iterative process involving both public participation and expert judgment, as shown in Table 1.

Establishing stakeholder involvement (for example, via working groups) is an important step in the process of developing indicators, because it provides stakeholders with a wide range of interests, opinions and experience with an opportunity to understand and explain issues of importance to them. This provides the stakeholders with a sense of ownership and control in the project, and increases the prospects of implementation and success. Each potential effect identified by a stakeholder is important to evaluating sustainability because each stakeholder needs to feel his or her concerns are taken seriously in order to promote the goal of developing collaborative and meaningful indicators and decisions or solutions. On the other hand, each stakeholder should recognize that some effects are more important than others, and in an environment of limited resources some setting of priorities needs to occur. Combining stakeholder involvement with information from experts (model outputs, qualitative information, and expert judgment) in an iterative fashion allows various viewpoints to be considered effectively and differences to be better negotiated.

We note however that even if one follows an approach like that sketched in Table 1, the problem of jointly assessing sustainability along different spatial scales is not resolved.

Table 1. Role of Technical Assessment and Stakeholder Involvement in the Determination of Important Indicators

Procedure	Description	Source
STEP 1	Inform Community about Economic/Ecological/Natural resource base	
	• Profile of economic base (jobs, incomes, taxes, etc.) • Profile of land-use/habitat in the community • Profile of natural capital inventory • Profile of critical natural capital indicators	*Using regional economic models, GIS, Natural Resource accounting and indicator systems.*
STEP 2	Determine Community Preferences	
	• Relative emphasis on environmental functions/values • Importance of specific land use/development patterns	*Participatory process involving community, political leaders, etc.*
STEP 3	Link functions/values to land use/habitat profiles.	*Using ecosystem assessment methods and landscape models.*
STEP 4	Link changes in land use/habitat profile with policy decisions, including transportation, zoning, taxes, protected areas and environmental restoration.	*Analyses of incentives, penalties, restrictions.*
STEP 5	Based on Community preferences (Step 2) and linkages between functions/values and land use (Step 3) and land use and policy (Step 4) evaluate the cost and effectiveness of policy alternatives.	*Uses spreadsheets & graphic displays of payoffs/ and $ and non-$ costs.*
STEP 6	Conduct sensitivity analyses to test responses of Step 5 results to decisions at other scales - state, national - to exogenous economic and environmental shocks, to shifting priorities, and to adaptive management.	*Uses spreadsheets & graphic displays of thresholds, decision-rules.*
STEP 7	Use results of Step 5 and Step 6 to inform community of opportunities, risks, tradeoffs, and costs associated with policy alternatives.	*Restart at Step 1 or leave community alone to make policy choices.*

A local community will come to one set of conclusions about an economic or environmental project, while the larger surrounding community may come to a very different conclusion depending on the direction of positive and negative flows (direct economic benefits and nonmarket spillovers). Which views should hold sway? There is no analytical answer to this question. Simply being able to track flows across spatial boundaries does not tell us how we should evaluate those flows, either locally or from a broader perspective. These are fundamentally values-based decisions reflecting the social, institutional, and political cultures that prevail (e.g., the federalist system in the US versus more centralized control in some Western European countries and the lack of strong national influence at present in Russia).

INDICATORS IN PRACTICE

An indicator points beyond what is actually measured to a larger phenomenon. Indicators *quantify* information so significant changes or differences in the larger phenomena are more readily apparent and can be compared; and they *simplify* information about complex phenomena to improve understanding and communication. Thus, an indicator can be defined as "something that provides a clue to a matter of larger significance or makes perceptible a trend or phenomenon that is not immediately detectable" (Hammond et al., 1995). Of particular importance are *leading indicators,* which can be used to refer to provide clues as to what important changes are likely to take place in the future. The range of *potential* leading indicators of movements towards or away from sustainability is limited only by imagination. On the other hand, the range of *practical* leading indicators of sustainability is limited by cost, data availability and reliability, and the level of social consensus about the interpretation and significance of what is being measured.

As already pointed out, a community becomes specialized and therefore dependent on activities, events, and policies that occur beyond its borders. Local economic activity and the sustainability of a community's general welfare often depend on both stocks and transboundary flows of natural resources, pollutants, intermediate and final products, and financial resources. Consequently, a community may have little or no control over the terms of trade for its exports and imports; financial flows to and from the area are likely to depend on the tax, spending, and subsidy policies of larger political entities; and community welfare may depend on transboundary movements of people, natural resources, wastes, and pollutants over which local control is limited. Clearly economic and environmental indicators are very interdependent.

Although there has been extensive experience developing the traditional measures of economic activity such as gross and net product, unemployment rate, median incomes, and savings rates, these measures provide only a partial picture of the economic aspects of sustainability. Especially at a local level, it is important to examine the spatial decomposition of important economic flows. For example, is income in a region high primarily because of inflows of outside largesse or other flows? (These could include tax breaks, income supports, remittances from workers abroad or other sources; see, e.g., King and Crosson 1995 for an illustration.) Is the community dependent on a natural resource (minerals or fish stocks, for example), which are subject to depletion or might otherwise become less available?

It is also important to decompose sources of economic change to understand robustness to future change. For example, how much of a region's growth is due to growth overall, to growth in a few sectors, and to a change in the regional mix of economic activity (Dunn 1980)? A similar decomposition of investment can reveal sensitivity to trends or cycles. Beyond these measures of economic activity, it also is important to consider leading indicators of changes in income distribution (for example, changes in educational achievement coupled with trends in sectoral activity and employment), as well as broader and more amorphous measures of social well-being (e.g., infant mortality, school violence).

Natural capital is comparable to manufactured capital or human capital in the sense that the environment generates diverse streams of products and services over time. The environment has value as a source of *inventories* of "raw materials" (e.g., timber, fish, beautiful views). It is valuable as *plant* and *equipment* because it includes all the necessary support systems to replenish these inventories (e.g., wetlands and coral reefs). Fundamental environmental processes (like carbon cycling) also act like basic *infrastructure* that sustains natural and economic systems and supports all other forms of biological and industrial productivity (e.g., biodiversity and water, nutrient, energy and carbon cycling).

Even those economists who believe in principle that monetary values can be attached to all these services acknowledge the practical difficulties of doing so. (For a discussion of the conceptual and practical problems of applying non-market valuation to wetlands and other natural assets, see Smith 1996.) On the other hand, simply positing fixed preservation rules for natural capital also is not efficient, for reasons noted in the previous section. It is therefore useful to consider how physical information about natural capital services might be used for priority-setting in natural capital management and sustainability assessment.

One useful way to proceed is to consider in a formalized fashion factors related to *Capacity*, *Opportunity*, *Payoff*, and *Equity* associated with given specific environmental functions (King, 1996). Site-specific features (e.g., soil type, vegetative cover, topographical features) determine the *capacity* to provide various functions; and landscape context features (e.g., proximity to other components of the natural and human landscape) determine if the environment will have the *opportunity* to provide these functions and strongly influences what *services* will flow from them, the *payoffs* that will result, and the *equity* of the distribution of benefits. For purposes of assessing the environment's value, therefore, some important and often overlooked questions involving the scarcity of the services it provides, the availability of perfect or close substitutes for them, the ability of the environment to recover or to be restored or replaced, and the capacity of humans to adjust and adapt to temporary or even permanent environmental changes, can and should be asked using this framework. The answers to such questions are location-specific and provide another basis for potential "leading indicators" of environmental value.

A brief example involving wetlands supporting waterfowl migration and nutrient trapping can illustrate the framework. *Capacity*: Does the wetland have the bio-physical conditions necessary to support waterfowl migration or trap nutrients? *Opportunity*: Is it located in a landscape where it will serve these functions (along a flyway or in a drainage with agricultural lands)? *Payoff*: How will providing this function at this location result in benefits to people? Will waterfowl increase or simply be diverted from elsewhere? Will the nutrient trapping provide a significant water quality benefit, or is the receiving water already damaged beyond recovery)? *Equity*: Who gains and who loses as a result of the environmental component providing the function at this location versus elsewhere or not at all? Often only questions regarding the capacity of a particular site or resource are asked, providing no insight into the benefits of protection (or leading to strange circumstances like the remediation of wetlands in areas where few if any people live and benefit from them, just because the functions are found there).

This framework emphasizes the attributes of a particular resource or site. For many purposes, it may be important to take a broader and longer perspective that also accounts for:

- the likelihood that broader landscape conditions may change (e.g., given two sites possessing the same capacity, opportunity, payoff and equity, one site may be selected for future development);

- the fact that different environmental components may be more or less vulnerable (exposed to change), resistant (able to withstand change), and resilient (able to recover from change); and

- the people who benefit from different environmental components have different capacities to adapt and to respond to change.

Again, the goal of effective sustainability assessment should be the devising of leading indicators for these factors.

CONCLUSIONS

Assessments of sustainability must have a spatial reference and a capacity to address economic, environmental, and other flows. As result, many issues such as spillover effects, distributional issues with regards to spatial externalities, and the appropriate geographic scale of policy responses need to be appropriately addressed. There is a need for getting working agreement on what should be measured and how to design manageable investigations into the state of economic, environmental and social systems in specific locations. Because the stresses on these systems and the risks they pose and consequences they have are very location-specific, so will be the kinds of factual issues that need to be addressed.

Once there is at least provisional agreement on what should be assessed, then information-gathering can proceed and debate can flourish about both the interpretation of the information received and its adequacy. For example, on the economic side one can look at the extent to which a region's economic base disproportionately lies in slower or faster growing sectors, and how the region is faring competitively relative to the larger economic system. With respect to environmental resources, one can try to identify those assets that are more crucial than others for continued economic progress and quality of life under the status quo. In both cases, a key question will be the capacity to assess and adjust to changing economic and environmental circumstances, including changes arising externally to the community, and to assess external effects arising in the community.

In all these assessments, it will clearly be important to look at how a particular region may be able to mask the unsustainability of its own activities by exporting environmental, economic and social problems to other areas, as well as to look at threats to local sustainability from outside the region. But these considerations will be only part of the story. Debates about how to judge sustainability will be an integral part of the assessment.

Implementing the approach we have outlined here will require a lot of learning by doing in identifying the factors that are important to assess without having too restrictive an interpretation of how the information should be weighed. Experience will be needed to determine whether and how this somewhat ad hoc but location-specific approach can provide useful information for decision-makers.

These observations lead to several tentative conclusions about the direction of future work to enhance sustainability assessment. So long as the capacity of integrated assessment frameworks is limited, it is important to increase basic empirical understanding of environmental-economic interactions. At the same time, practical concerns about sustainability cannot be put on indefinite hold pending the development of a definitive data set and analytical framework. This suggests in turn the need for developing more ad hoc but still useful means for assessing sustainability, both locally and at a larger scale. Accomplishing this will require more agreement than currently exists in regard to what kinds of phenomena should be targeted for assessment and how they should be assessed. In short, the question of how to provide information that can be used to assess sustainability cannot be divorced from the question of what sustainability entails.

REFERENCES

Asheim, G. B. 1994. "Net National Product as an Indicator of Sustainability," *Scandinavian Journal of Economics* vol. 96, pp. 257-265.

Ayres, R. U. and A. V. Kneese. 1969. "Production, Consumption and Externalities, *American Economic Review* vol. 59, pp. 282-97.

Bohi, D. R. and M. A. Toman. 1984. *Analyzing Nonrenewable Resource Supply* (Washington, D.C., Resources for the Future).

Clark, C. W. 1990. *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*, 2nd ed. (New York, N.Y.: Wiley).

Coughlin, C. C., and T. B. Mandelbaum. 1991. "A Consumer's Guide to Regional Economic Multipliers," Federal Reserve Bank of St. Louis (January/February), pp. 19-32.

Cumberland, J. H. 1966. "A Regional Inter-Industry Model for Analysis of Development Objectives," *Regional Science Association Papers* vol. 17, pp. 65-95.

Daly, H. E. 1968. "On Economics as a Life Science," *Journal of Political Economy* vol. 76, pp. 392-406.

Dasgupta, P. S. and K.-G. Maler. 1991. "The Environment and Emerging Development Issues," in *Proceedings of the World Bank Annual Conference on Development Economics 1990* (Washington, D.C.: The World Bank).

Duchin, F. 1996. "Structural Economics: A Strategy for Analyzing the Implications of Consumption." Draft manuscript (July 15).

Dunn, E. S. 1980. *The Development of the US Urban System* (Baltimore, Md.: The Johns Hopkins University Press for Resources for the Future).

Faber, M. and J. L. R. Proops. 1993. *Evolution, Time Production and the Environment*, 2nd ed. (Heidelberg: Springer-Verlag).

Forsund, F. R. 1985. "Input-Output Models, National Economic Models and the Environment," in A. V. Kneese and J. L. Sweeney, eds., *Handbook of Natural Resource and Energy Economics* (Amsterdam: Elsevier).

Hammond, A., A. Adriannse, E. Rodenburg, D. Bryant, and R. Woodward. 1995. *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development* (Washington, D.C.: World Resources Institute).

Howarth, R. H. 1996. "Climate Change and Overlapping Generations," *Contemporary Economic Policy* vol. 14, pp. 100-111.

Isard, W. 1969. "Some Notes on the Linkage of the Ecologic and Economic Systems," paper delivered to the Regional Science and Landscape Analysis Project, Harvard University, June 27.

James, D. 1985. "Environmental Economics, Industrial Process Models and Regional-Residuals Management Models," in A. V. Kneese and J. L. Sweeney, eds., *Handbook of Natural Resource and Energy Economics* (Amsterdam: Elsevier).

King, Dennis M. 1996. "Comparing Ecosystem Services and Values," paper prepared for U.S. Department of Commerce (December).

King, D. M. and P. R. Crosson. 1995. "Natural Capital Indicators," paper prepared for the Resource Policy Consortium, World Bank, Washington, D.C. (June 12).

Kopp, R., A. Krupnick, and M. Toman. 1997. "Cost-Benefit Analysis and Regulatory Reform," *Human and Ecological Risk Assessment* vol. 3, pp. 787-852.

Leontief, W. 1936. "Quantitative Input-Output Relations in the Economic System of the United States," *Review of Economics and Statistics* vol. 18, pp. 105-125.

Miller, R. E. and P. D. Blair. 1985. *Input-Output Analysis: Foundations and Extensions* (Englewood Cliffs, New Jersey: Prentice Hall).

Munda, G. 1996. "Cost-Benefit Analysis in Integrated Environmental Assessment: Some Methodological Issues," *Ecological Economics* vol. 19, no. 2, pp. 157-168.

Norton, B. G. and M. A. Toman. 1997. "Sustainability: Ecological and Economic Perspectives," *Land Economics*, vol. 73, no. 4, pp. 553-568.

Organization for Economic Cooperation and Development (OECD). 1991. *The State of the Environment* (Paris: OECD).

Pearce, D. W. and G. D. Atkinson. 1993. "Capital Theory and the Measurement of Sustainable Development: Some Empirical Evidence," *Ecological Economics* vol. 8, pp. 103-108.

Pearson, P. J. G. 1989. "Proactive Energy-Environment Policy Strategies: A Role for Input-Output Analysis," *Environment and Planning* vol. 21, pp. 1329-1348.

Pezzey, J. C. V. 1994. "The Optimal Sustainable Depletion of Nonrenewable Resources." 5th EAERE Annual Meetings, Dublin, Ireland.

Pezzey, J. C. V. 1998. "Stripping Resources and Investing Abroad: A Path to Sustainable Development?," in M. Acutt and P. Mason, eds., *Environmental Valuation, Economic Policy and Sustainability* (Cheltenham, U.K.: Edward Elgar), forthcoming.

President's Council on Sustainable Development (PCSD). 1996. *Sustainable America: A New Consensus for Prosperity, Opportunity, and a Healthy Environment* (Washington, D.C.: Government Printing Office).

Smith, R. 1995. "Waste Accounting Within an Input-Output Framework: Strengths and Weaknesses," Second Meeting of the London Group on Natural Resource and Environmental Accounting Conference Papers, Washington, D.C. (March 15-17).

Smith, V. K. 1996. *Estimating Economic Values for Nature* (Cheltenham, U.K.: Edward Elgar).

Toman, M. A., J. Pezzey, and J. Krautkraemer. 1995. "Neoclassical Economic Growth Theory and 'Sustainability'," in D. Bromley, ed., *Handbook of Environmental Economics* (Oxford, U.K.: Blackwell).

Victor, P.A. 1972. *Pollution: Economy and Environment* (Toronto, Ont.: University of Toronto Press).