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Critical environmental indicators: performance indices and assessment models for sustainable rural development planning☆

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Abstract

Sustainable development planning must be based on environmental and biophysical baseline indices that effectively define comparative development potential and environmental constraints. As such, indices must define the comparative advantage of the natural resource base and measure the fundamental capacity to sustain production rates of natural resource goods and services used to create societal well being. Complex biophysical and socioeconomic characteristics affect the identification and selection of sustainable development strategies. When derived from effective baseline indicators, indices may be used to define the spatial and temporal distribution of economically viable production opportunities and may be expressed in derived indices that realistically describe basic production opportunities and guide the selection of feasible, long-term development strategies. Specifically, representative indices are critical in the identification of development goals and realistic objectives and can be used to evaluate, select and implement sustainable development strategies and plans. It is stressed that the relevancy and effectiveness of public policies depend on the identification of representative evaluation models and baseline indices to define development strategies that are both environmentally sustainable and economically viable. In this context, the role of baseline indicators that define natural resource production capacities is discussed. This includes potential resource uses, derived benefits and their economic and environmental impacts. Key thematic indicators are suggested that may be especially useful in identifying development alternatives and impacts. This suggested that clearly defined environmental pollution limits or impact standards be used to define public risk tolerance limits and carrying capacity constraints. It is argued that these measures may be more effective in directing policy choices than economic valuation of non market goods and services that represent environmental externalities associated with resource exploitation options and economic development strategies. To this end, examples of thematic indicators and derived indices are introduced that may prove effective in resource assessment, economic evaluation and strategic development planning.

Keywords: Resource production capacity; Environmental quality; Environmental indicators; Public policy; Impact assessment; Economic development planning

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1. Introduction

The primary goal of development planning is to improve the quality of life of human populations by means of a systematic evaluation, selection and implementation of sustainable development alternatives that reflect both environmental constraints and opportunities. Here, sustainable development refers to the promotion of development policies and plans with carefully defined objectives that aim to achieve a sustainable flow of goods and services that enhance quality of life. More precisely, sustainable development must ensure that public policies are based on the selection of development alternatives, which are both ecologically sustainable and economically viable. As such, sustainable development addresses the development and management of environmental resources to ensure or enhance the long-term productive capacity of the resource base with the goal to improve long-term societal wealth and well being (Schultink, 1992).

A primary challenge in this public policy formulation process is to balance environmental productive capacity (e.g. sustainable production rates based on certain input regimes and management practices) and the derived supply of natural resource goods and services with demographic demand, thereby ensuring that sustainable production capacities are not exceeded. A good example of this approach is the FAO study of the capacity of land in the developing world to support potential populations (Higgins et al., 1982).

In a policy analysis context, determining supply means a systematic assessment of the resource production capacities by location and over time. To be effective, the information resulting from this assessment must be expressed in spatially referenced quantitative indicators that directly reflect resource production outputs (complex goods and services). To be realistic, production scenarios must represent input scenarios and management regimes that do not degrade the long-term production capacity or the environmental quality (including the genetic diversity) of the natural resource base. Social demand needs to be related to the sustainable supply of natural resource goods and services: specifically, the resource capacity to affect quality of life — creating a better place to live, a location capable, productive and efficient in meeting complex human needs. Fundamentally, quality of life must reflect the comprehensive continuum of human needs: primary- food, clothing and shelter; secondary- educational opportunities, health needs and environmental risks; and tertiary- environmental quality and amenity resources and associated recreational opportunities.

For the same reasons, sustainable planning should include systematic production capacity assessment as an integrated component in the hierarchical process of public policy formulation and development planning (Fig. 1).

A great number of factors affect natural resources production capacity, economic supply and demographic demand. Some of the basic factors are identified later (Fig. 2). The challenge, therefore, is to define production capacity in the form of relevant productivity and supply indicators, which, in turn, may be used to represent sustainable production scenarios to meet final consumer demand.

2. Measuring natural resource production capacity

Any systematic attempt to address sustainable development planning should include baseline performance indicators and representative productivity indices. In rural areas, this means defining the productivity of the renewable land resource base and its derived uses, such as represented by the products and services from the agricultural, forestry and tourism sectors, as well as outputs (ecological functions and derived social values) from natural ecosystems. Realistically, this should reflect both sustainable resource production capacity and economic feasibility. In rural sector planning, this may include the following assessment phases:

- assessment of basic agroecological production capacity on a crop or commodity-specific basis;
- assessment of sustainable productivity levels using adjustment for locally relevant production opportunities and input constraints (e.g. irrigation, fertilization, technology, capital); and

- economic viability of production options (input costs and product prices).

This relationship is further identified in Fig. 3.

An example of assessing basic productivity and its long-term sustainability in the form of relevant indicators can be provided in the form of crop productivity or farming systems analysis. For instance, in agroecological production capacity assessment, the genetic potential of crops grown under specific water supply (deficit) conditions is predicted. The agroecological parameters that primarily affect this biophysical production function are soil type (texture), climate (rainfall, temperature, relative humidity, solar radiation, wind speed) and local topography (slope gradient and

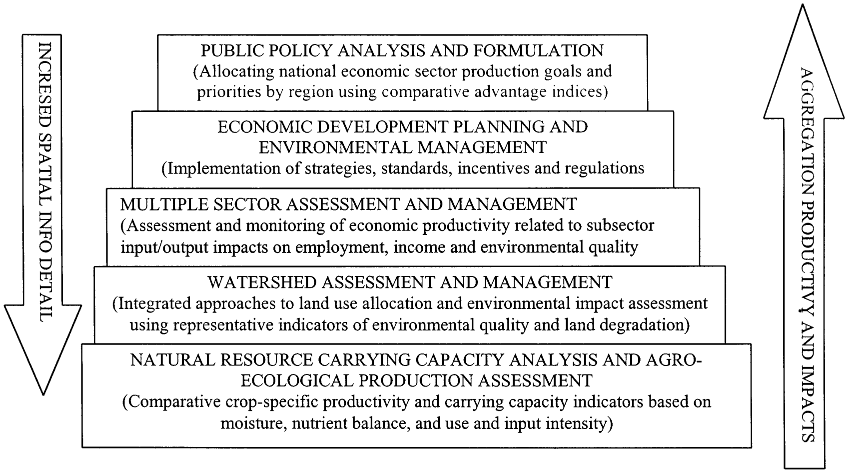

Fig. 1.

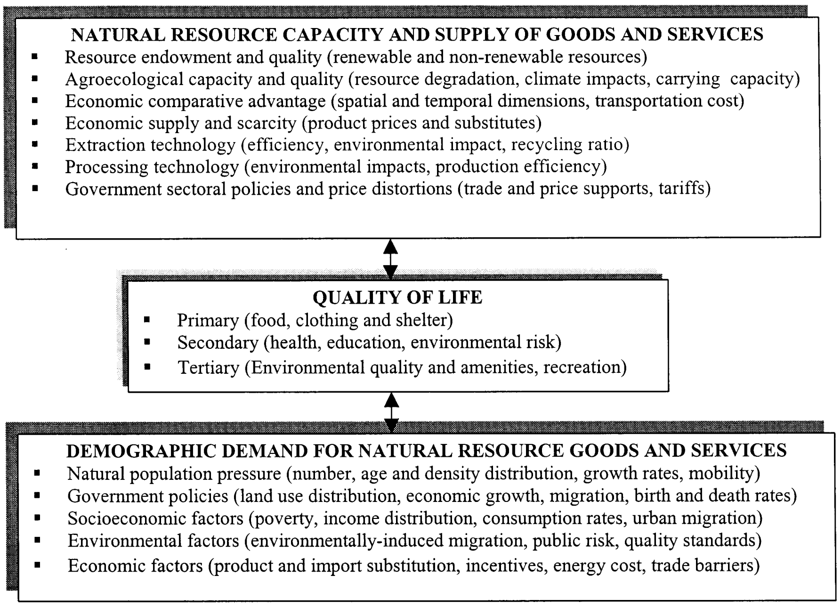

Fig. 2.

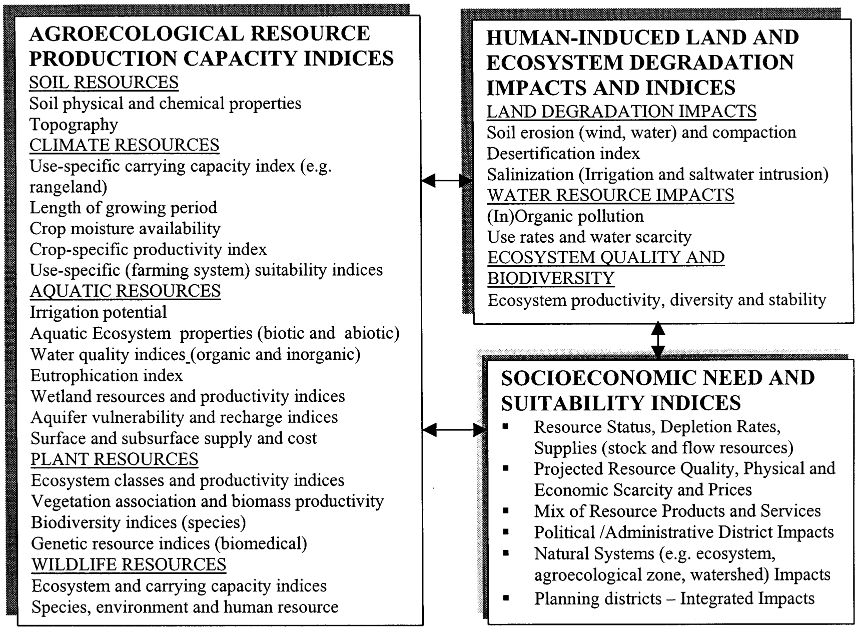

Fig. 3.

aspect). This initial estimate of crop productivity does not assume limitations with regard to farm management practices — nutrient deficits, salinity impacts or mulching — or land degradation considerations. This basic relationship is identified by the crop yield response formula as theoretically detailed or in adapted computer-based crop yield models (Doorenbos and Kassam, 1979; Schultink et al., 1987; Schultink, 1987a,b) as:

$$\left(1-\frac{y_a}{y_m}\right)=k_y\left(1-\frac{ET_a}{ET_m}\right)$$

where y_a is the actual harvested crop yield, y_m the maximum harvested crop yield, k_y the genetically determined yield response factor, ET_a the actual evapotranspiration and ET_m is the maximum evapotranspiration.

The crop yield response factor is based on extensive field trials covering a variety of soils and growing conditions and reflects high yielding varieties well adapted to local agroecological conditions.

Assessment of sustainable productivity levels includes yield adjustment for locally relevant production opportunities and input constraints (e.g. irrigation, fertilization, technology and capital). In essence, this includes a compilation of:

- additional biophysical factors indirectly affecting crop moisture availability, such as soil depth/texture, organic content, net irrigation application, rooting depth, water infiltration rate based on slope/textural classes and crop nutrient availability;
- socioeconomic conditions that affect the farm input level and long-term effectiveness of management practices (e.g. fertilizer and pesticide inputs, cropping intensity, labor or capital constraints, profit margins, land degradation), which affect sustainable productivity; and
- off-farm impacts such as environmental externalities resulting from soil erosion, fertilizer impacts, pesticide applications, or general impacts on water quality and availability and impacts on biodiversity, ecosystem integrity, or stability.

This resource productivity assessment must be further expanded into a socioeconomic evaluation of needs and suitability. Here, need addresses the social demand resulting from expressed social expectations related to the quality of life and associated availability and price or goods and services, while suitability reflects the economic viability of production opportunities, such as land-use types or farming systems.

The use of the comprehensive and relevant indicators already suggested must be incorporated into the larger decision-support framework for policy analysis and rural development planning. In essence, this transforms the reductionistic approach in the developing world — reducing problem-solving to a segmentation of the problem by using descriptive indicators — to a holistic or systems approach. A holistic approach uses composite indicators of social preferences and performance and can, therefore, accommodate a variety of personal assumptions, opinions and group desires, accounting for public policy trade-offs involving complex costs, benefits and risk.

A key requirement in this process is that environmentally referenced indicators, reflecting economic productivity opportunities and environmental impacts, by agroecological zones, watersheds or major ecosystems, must be directly related to political or administrative regions for the comparative analysis of relevant socioeconomic impacts and as the basis for strategic planning and implementation.

As pointed out earlier, this relationship (Fig. 4) among indicators is reflected in the hierarchy of planning and management and may also be illustrated by the following analytical sequence of single-issue resource management to comprehensive planning. The key challenge, then, is to define specific management objectives at each level that operationalize private and public development goals. This involves seeking complimentarity of socio-economic and environmental goals that are specifically identified as indicators representing needs and opportunity, as well as measures of performance and impact. For example, in sustainable land management, this would involve indicators that measure land degradation trends and quality and denote intervention needs and development opportunities, representing various land-use types as natural or managed production ecosystems. Fundamentally, use capacity is reflected in land quality indicators representing a potential sustainable use condition of the landscape on a comparative basis and is expressed at the local, regional or national scale. Given a specific level of scale, land capacity or quality may include indicators of nutrient and water balance, crop and forest yield trends, unrealized production potential based on certain land-use type and management intensity, natural grassland (range) carrying capacity, land cover and biological diversity and various indicators of environmental quality.

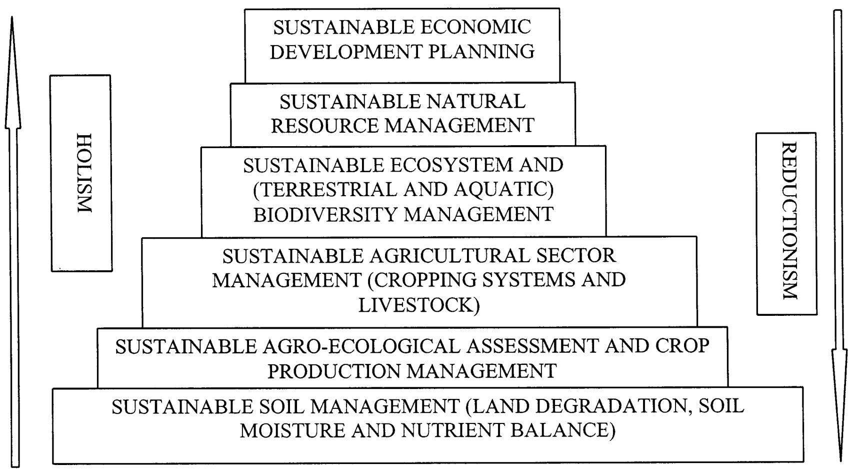

Fig. 4.

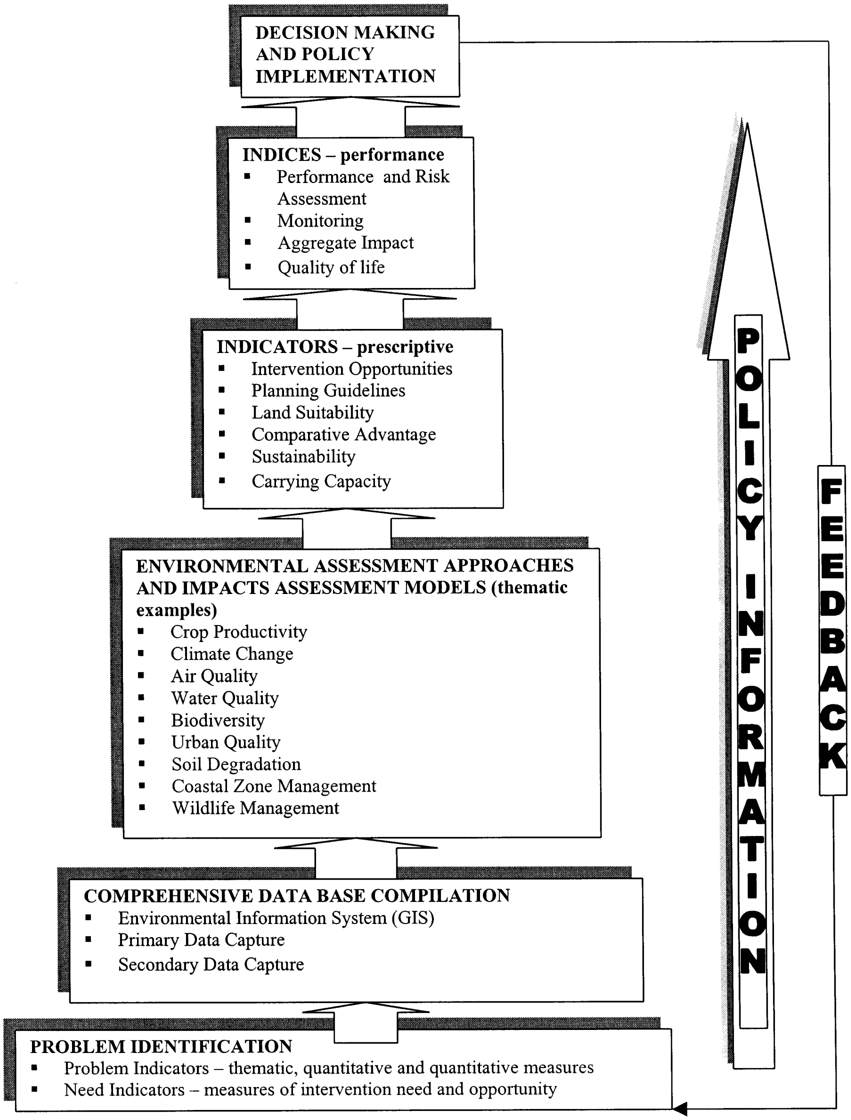

Fig. 5.

3. Environmental information, indices, indicators and public policy

One of the most significant challenges in development planning is to derive information economically and ensure that it is thematically, spatially and temporally relevant in supporting policy analysis and decision-making. Beyond the traditional data quality standards of precision and accuracy, it is important to identify the minimum information content necessary to meet decision-support objectives, at a given point in time. It may be argued that any redundant information constitutes inefficient use of human and capital resources.

In the process of compiling information, a distinction has to be made with regard to the sequence and characteristics of basic data capture and analysis and the use and distribution of relevant information. This process sequence is illustrated in Fig. 5. It is especially important to differentiate among the various information compilation steps, namely:

- the use of relevant, descriptive qualitative and quantitative problem indicators in the problem identification stage;
- problem-oriented fact finding involving the use of primary and secondary data sets compiled in a spatially referenced information system (geographical information system), linked with analytical performance assessment models, such as agronomic productivity and socioeconomic impact assessment models;
- the compilation of single indicators or composite prescriptive indices that identify potential solutions and alternative problem-solving approaches; and
- the selection of planning and implementation alternatives based on composite performance indices that reflect planning impacts, intended public policy consequences and the aggregate impact on the quality of life over time, by location and populations affected.

The formulation of the latter two categories — involving the identification of potential solutions, the selection of preferred alternatives and courses of implementation — must be addressed effectively by the compiled information. To this end, consideration should be given to the formulation of a national spatial data infrastructure (NSDI) that may be viewed as a network of spatial data infrastructures (SDIs) linked to address specific applications. The primary purpose of a SDI is to provided improved access to spatial data (reflecting time, cost, quality, relevancy and standardization issues) and support NSDI policy analysis needs on a economic sector or issue basis (e.g. environmental impact analysis, rural development planning, transportation planning or agricultural or tourism sector analysis). This involves the identification of critical qualitative and quantitative indicators and derived indices, as viewed from the perspective of the various national or regional agencies with associated mandates in economic development and environmental protection.

Composite indices designed to meet decision support requirements may reflect traditional economic measures of economic efficiency and also measures of public risk of the impact of human activities or development actions on the environment. Rather then viewing risk solely as a physical health factor, it is suggested that risk in policy formulation reflects the broader view of human well being or quality of life. More recently, the issue of social equity in involuntary environmental risk exposure has received increased attention.

Elements that may be included into this assessment are water and air pollution, environmental disease vectors and their controls, occupational health, food safety and traffic safety. A modified risk equation (Schultink, 1992) can be used in this process to assess the composite indicator of environmental risk as:

$$R_n = \sum_{i=1}^{n} r_n \times p_n \times v_n - t_n$$

where r is the expected value of the magnitude or degree of risk (expressed as social cost), p the exposure probability (expressed as frequency or probability of occurrence (%); this factor may be weighted for large impact areas where significant spatial decay of impacts is anticipated), v the vulnerability of the target population (e.g. age and weight factors), t the potential risk reduction factor (e.g. prevention or mitigation policies) and n is the number of risk variables involved.

Risk assessment must be viewed as a distinctly different component in public policy studies than risk management. The former is a scientific assessment of potential health risk that may result from development impacts on the environment, while the latter addresses concerted public policy efforts to reduce risk through education, regulation and mitigation. Risk management uses the scientific results of risk assessment as expressed in comparative indices, while assessing the implications using economic, social and legal considerations to formulate policy decisions and regulatory interventions.

4. Emerging environmental policy perspectives and analytical needs

Globally, environmental quality and public health risk associated with the impacts of public policy on the broader notion of quality of life, are receiving increased attention. In the US and Canada and within the European Union (EU), most important policy initiatives address deteriorating air and water quality, restoration of ecosystems functions and nature preservation needs.

In the EU, legislation has already achieved a considerable degree of harmony, but significant differences remain among member states as to their economic ability and political willingness to create an effective environmental policy agenda for the late 1990s and beyond. Principally, socioeconomic disparities, differences in settlement densities and environmental quality concerns are the core of the problem. The higher-income regions of northern Europe are critically reviewing the agricultural sector in transition. Reduced gross national product shares of the agricultural sector, environmental nutrient loadings by traditional farming systems and bio-industry and a shift in societal land-use perspectives are all causing dramatic changes in land-use policies. Implications of recent environmental policy perspectives reflect new economic opportunities while explicitly recognizing the social cost of environmental externalities associated with current land-use distribution and practices. This includes: (a) land-use conversions from traditional agricultural to seasonal recreational and environmentally compatible uses through ecosystem restoration to realize new economic potentials; and (b) changing policy priorities of a leisure society concerned with environmental quality impacts within the broader context of public risk and quality of life.

In the US and Canada, environmental policy emphasis is primarily directed toward the prevention of water and air pollution, rather then toward a proactive, comprehensive regulation of land-use impacts on environmental quality. Here, as in many other industrialized nations, significant land-use impacts are caused by uncontrolled regional growth patterns, agricultural land conversion and urban sprawl, urban decay and industrial pollution and public policies permitting unsustainable use of natural resources.

The challenge, then is to evolve an integrated systems approach to natural resource evaluation and impact assessment that fosters the development of a decision support system that is effective in making informed public policy choices. Such a policy analysis system, as outlined later (Fig. 6), consists of three major functional components, comprising diagnostic, prescriptive and performance indicators and their derived resulting indices. It includes: (1) a comprehensive resource evaluation system; (2) a land-use evaluation system; and (3) a public policy analysis system.

Public interests largely reflect the long-term environmental stewardship principle that includes public interests in resource conservation and environmental quality. Private interests largely reflect more short-term economic interests that are directly affected by ownership rights, laws and regulations. In this regard, the goal of public land-use policy is to formulate multi-jurisdictional, resource policy systems that include the institutional controls and capacity to:

- identify the comparative advantage of resource use opportunities (e.g. resource endowment, use capacity and use efficiencies) in the context of environmental constraints (e.g. carrying capacity and resource depletion rates) — the resource evaluation framework;
- evolve guidelines and decision-support systems to evaluate public and private-sector benefits (e.g. benefit/cost, benefit/risk) of land-use alternatives and associated environmental impacts — the policy analysis framework; and
- development implementation and evaluation through effective development strategies, land-use plans, laws and regulations and performance monitoring — the policy implementation framework.

In general, public development policy attempts to guide the identification and selection of 'best resource use' options reflecting both public land-use alternatives and the aggregate socioeconomic and environmental impacts of private land-use choices. It aims to mobilize the production of goods and services as resource outputs to meet societal needs and to improve resource productivity, input and management efficiency, while attempting to optimize product distribution and availability.

In this context, environmental assessment is a systematic process of fact finding, interpretation and identification of development alternatives and associated impacts. This process is by nature holistic and multidisciplinary, reflecting the best fundamental understanding of the structure and dynamics of ecosystems and the linkages among a complex set of biotic and abiotic factors.

Sustainable development fundamentally reflects this understanding and, therefore, the perceived opportunities and environmental limits that provide guidelines for improved decision-making, environmental management and development planning. This understanding is never absolute, lacking essential knowledge about complex ecological relationships, complicated by spatial and temporal inaccuracies, affected by adaptive impacts and policy changes and influenced by changing valuations of public benefits, costs and risks.

To effectively challenge this decision-making complexity, a systems approach to economic development and environmental assessment is suggested. The approach should be:

- issue-oriented to improve our ability to identify the qualitative and quantitative dimensions of the problem(s);
- diagnostic in its analytical approach to identifying potential solutions that are sustainable and economically viable; and
- focused on problem-solving by providing the minimum information needed to make informed decisions.

5. Economic development and environmental management: a synthesis of models and indicators

Improving quality of life requires that economic development and environmental management objectives are combined and operationalized into a

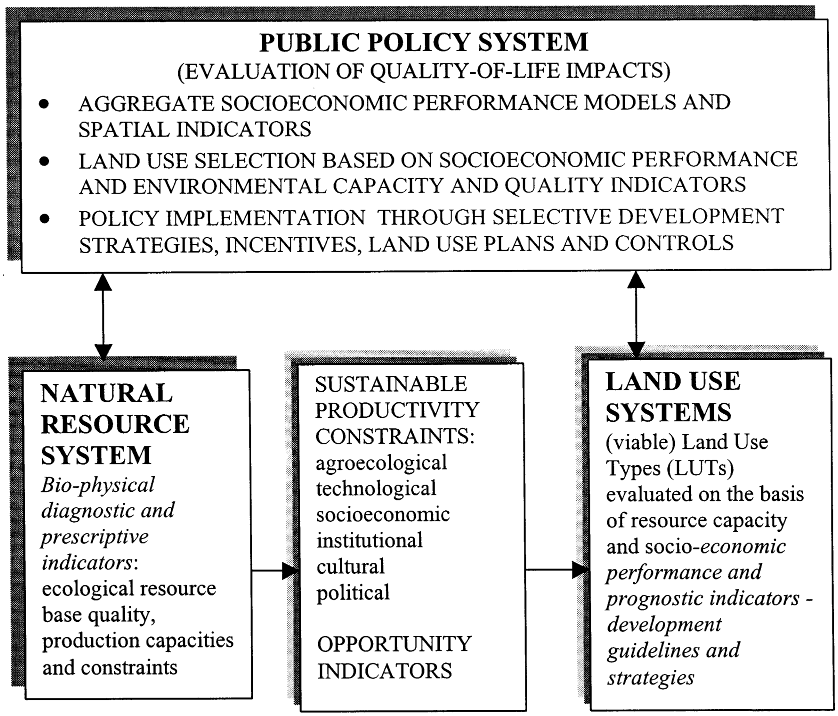

Fig. 6.

comprehensive public policy evaluation framework. As Adam Smith recognized more then 220 years ago (Smith, 1977), fundamental differences in labor availability and resource endowment account for differences in the creation of wealth by nations. In the early 1990s, three major capital components were identified as fundamental in the creation of wealth: produced assets, natural capital and human resources (World Bank, 1995; Serageldin, 1996). The relative importance of natural capital is more important in less developed nations or world regions. For instance, while in the US and Canada and western Europe natural capital accounts for only a 2–5% share of national wealth per capita, it accounts for as much 16–21% in south Asia and west Africa (World Bank, 1997). Therefore, in order to evolve sustainable development policies, the identification of economic development potential must include indices of comparative resource endowment, resource production capacity and environmental constraints to productivity and economic efficiency.

Resource capacity and environmental constraints can often be identified using biophysical spatial indices describing physical production functions, while economic development focuses primarily on aspects of socioeconomic feasibility and social benefits derived, including production efficiencies and measures of economic returns. This two-fold policy framework of environmental impact and economic development implies that relevant models and spatial indicators should be identified which may be used to identify public needs and economic opportunities.

After the identification of resource production capacities and sustainability constraints, the primary emphasis of development policy is on the economics of land evaluation — defining economic viability in the form of comparative socioeconomic indicators that are environmentally and spatially referenced. In this process, the performance characteristics of the single production entity (single enterprise) or of the aggregate level (farming system stratum, administrative district, or region based on a current or alternative mix of land-use options) are compared. Dominant analysis tools at the single production unit level include:

- land rent analysis: single land-use unit or the aggregate (net surplus of revenues);
- enterprise budget analysis: net farm income, includes variable and fixed cost;
- partial budgeting: single or aggregate, assesses impact of single or multiple (partial) variables;
- general benefit/cost analysis using present values; and
- gross margin analysis: assessment of a given farming system's gross margin: output ($US) minus variable cost.

Representative samples of the single enterprise results (farming system or land-use types) can be aggregated using to various levels, including agroecological zone, watershed or political/administrative district by using updated land-use maps.

At the sectoral or regional level, emphasis may be placed on comparing the aggregate impact of development strategies such as import substitution or productivity enhancement. Examples include the following.

- *Linear programming*. The aggregate (regional or agroecological) assessment of the productivity optimum for a certain crop mix subject to input constraints. Here, a predefined objective function is used to maximize (e.g. income or profit) or minimize (e.g. cost of production) subject to resource availability, production inputs and other constraints. The solution is aggregate in nature but may be used to identify the distribution of specific land-use alternatives based on land suitability rankings. This analysis is useful in developing nations because of the limited data requirements.
- *Input/output analysis*. The aggregate assessment of the regional or national impact of development strategies on employment and income distribution using intersectoral linkages driven by demand or supply considerations and intersectoral income and employment multipliers. Input/output analysis constitutes a systematic method of analyzing interrelationships between sectors in the economy. The method focuses on the tracing of the amount of product required of each sector to meet the demand of final users. Because each sector is linked to every

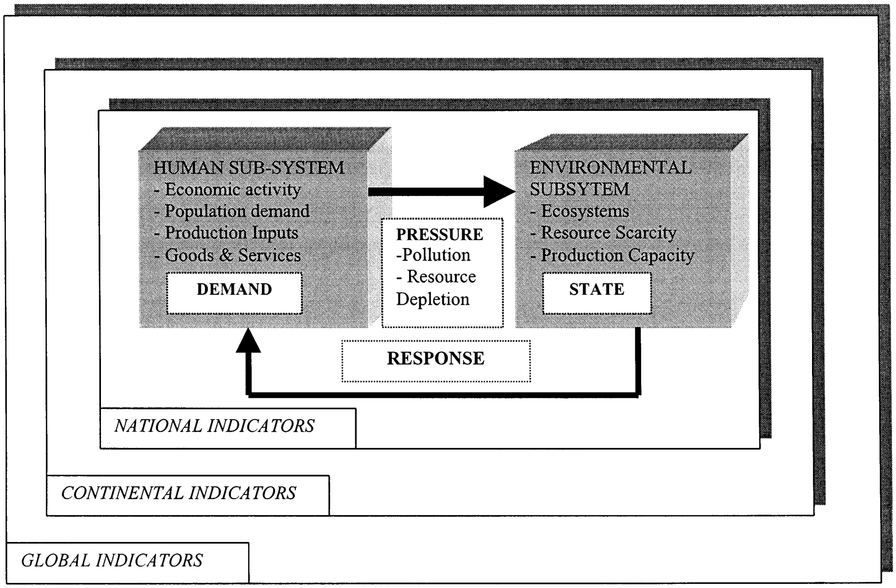

Fig. 7.

other sector in the economy, it is possible to quantify the direct and indirect effects of meeting this final demand. Effects include income and employment multipliers permitting the evaluation of impacts resulting from development options (e.g. sector investments, economic diversification, value-added initiatives in processing).

Since the 1960s, increasing attempts have been made to include environmental considerations into the economic analysis of natural resources, specifically to incorporate development or project externalities in the form of social costs (diseconomies) and social benefits (opportunity costs). This poses the challenge to 'value' resource loss (e.g. contingent value) or qualify alternative trade-offs for locations and countries in different development stages. It may be questioned how realistic and practical this effort is in deriving information for decision-making beyond the project context. It can be argued that in a broader public policy context, it may be more effective to set clearly defined environmental pollution limits and acceptable comprehensive impacts (e.g. resource impact, watershed, or environmental quality indicators). These limiting indicators can then be used to define exploitation limitations and carrying capacity constraints to define economic development strategies that are environmentally sustainable and economically viable.

This notion is not unlike the thematic and systemic indicator approach identified by various practitioners. For instance, the US agency for international development (USAID) compiled a set of indicators for various program objectives to evaluate the environmental performance of development programs (USAID, 1995, 1996). Indicator sets have also been developed in Canada, the Netherlands and the Nordic countries. The conceptual framework advanced by the OECD addresses the Pressure–State–Response linkages. This approach (Fig. 7) could be used as an international comparative framework to assess: (a) issue-based indicators of change or stress ('biophysical system state', e.g. urban air quality emissions); (b) related impacts of human activities (measured by pressure indicators, e.g. status VOC, NOx or SOx concentrations); and (c) resulting policy responses (e.g. transportation alternatives, fuel taxes, subsidies).

Although the level of aggregation differs, all approaches address policy themes such as transportation planning, energy use and environmental quality issues. Examples of thematically aggregated indicators include single and composite indicators for climate change, ozone-layer depletion, eutrophication, acidification, toxic contamination and dispersion, urban environmental quality, biodiversity, cultural and natural landscapes, waste disposal, forest resources, fisheries resources, disturbance of local environments, sectoral indicators, human health and well being and resource sustainability. Spatial aggregation of indicators can be accomplished starting at the local administrative district for socioeconomic indicators, while biophysical indicators may be aggregated at the management unit (e.g. watershed or ecosystem) level, both representative of the 'system status' of the targets (spatial units) of policy formulation.

Systemic indicators are primarily designed as diagnostic tools, i.e. to derive a composite measure of a system's status and express its degree of vitality or stress. Examples include indicators and trends for wealth and savings, material flows and energy or nutrient balances.

These indicator approaches offer the most promising tools in policy analysis and decision support. They can be used to quantify trends and spatial impacts of public policies, while reducing the subjective element in public policy formulation by identification of objective diagnostic standards and measurable goals and objectives.

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