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The sustainomics trans-disciplinary meta-framework for making development more sustainable: applications to energy issues

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Abstract: This paper describes sustainomics as ‘a transdisciplinary, integrative, balanced, heuristic and practical meta-framework for making development more sustainable’. The neologism helps to focus attention explicitly on sustainable development, and avoid the implication of any disciplinary bias or hegemony. The paper sets out some key constituent elements of sustainomics and how they might fit together. Sustainability criteria, applicable to the interlinked panarchy of economic and environmental systems, play an important role in the sustainomics framework. Environmental and social sustainability focus on the overall health of ecological and social systems, with emphasis on increasing resilience to withstand shocks and reduce vulnerability. Economic sustainability aims to maximize the flow of income that could be generated while at least maintaining the stock of assets (or capital) that yield these beneficial outputs. Equity and poverty are also key issues. All these concepts are integrated through two broad approaches involving optimality and durability. Sustainomics helps decision-makers to focus on the structure of development, rather than just the magnitude of economic growth (conventionally measured). The framework facilitates the incorporation of ecological and social concerns into the decision-making process of human society. Operationally, it plays this bridging role by enabling implementation of sustainability assessments, especially through the mapping of the results of environmental and social assessments onto the framework of conventional economic analysis. These concepts are illustrated through case studies involving energy problems across a full range of spatial scales. At the global-transnational level, the first case study examines the interplay of optimality and durability in determining appropriate global GHG emission target levels, and the second explores methods of combining efficiency and equity to facilitate South-North cooperation for climate change mitigation. At the national-economy level, the third study describes how the action impact matrix may be used for policy analysis, and the fourth sets out approaches for restructuring growth to make long-term development more sustainable. On the subnational-sectoral scale, the fifth case outlines methods for achieving sustainable energy development in Sri Lanka, and the sixth examines rainforest management in Madagascar. Finally, at the project-local level, multi-criteria analysis is applied to a fuel-wood stove project, and to compare small hydropower projects, using relevant economic, social and environmental indicators.

Keywords: sustainable development, sustainable energy, sustainomics.

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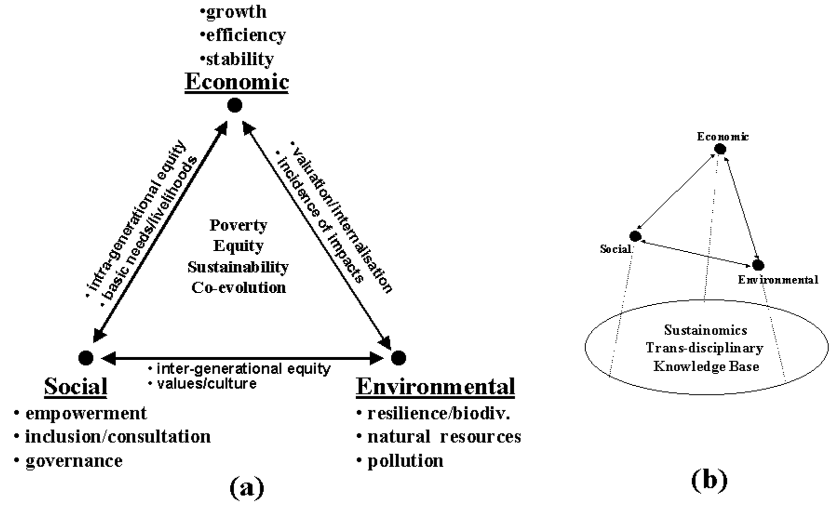
1 Basic framework

World decision-makers are looking for new solutions to many critical problems, including traditional development issues (such as economic stagnation, persistent poverty, hunger, malnutrition, and illness), as well as newer challenges (such as worsening environmental degradation and accelerating globalization). One key approach that has received growing attention is based on the concept of sustainable development or 'development which lasts'. Following the 1992 Earth Summit in Rio de Janeiro and the adoption of the United Nations' Agenda 21, sustainable development has become well accepted worldwide (WCED, 1987; UN, 1993).

Although no universally acceptable practical definition of sustainable development exists as yet, the concept has evolved to encompass three major points of view: economic, social and environmental, as represented by the triangle in Figure 1a (see for example, Munasinghe, 1993). Each viewpoint corresponds to a domain (and system) that has its own distinct driving forces and objectives. The economy is geared mainly towards improving human welfare, primarily through increases in the consumption of goods and services. The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social domain emphasizes the enrichment of human relationships and achievement of individual and group aspirations.



(a) (b)

Figure 1 (a). Elements of sustainable development
1 (b). Sustainable development triangle supported by the sustainomics framework.
Source: adapted from Munasinghe [1993, 1994]

Meanwhile, energy has emerged as one of the key resources whose use affects the economic, social and environmental dimensions of sustainable development. First, it has long been perceived as a major driving force underlying economic progress. Second, energy production and use are strongly interlinked with the environment. Third, energy is a basic human need, which significantly affects social well-being. In recent times, growing energy demand has also become associated with global climate change, which poses an unprecedented challenge to humanity. The wide-ranging potential impacts of energy production and consumption on sustainable development suggest that the linkages between these two topics need to be critically analysed. Accordingly, this paper sketches out a transdisciplinary meta-framework (named sustainomics) and seeks to apply it to the nexus of sustainable development and energy (including climate change).

Given the lack of a specific approach or framework that attempts to define, analyse, and implement sustainable development, Munasinghe (1993, 1994) proposed the term sustainomics to describe 'a transdisciplinary, integrative, comprehensive, balanced, heuristic and practical meta-framework for making development more sustainable.' The multiplicity and complexity of issues involved cannot be covered by a single discipline. Hitherto, multidisciplinary approaches involving teams of specialists from different disciplines have been applied to sustainable development issues. A further step has been taken through interdisciplinary work, which seeks to break down the barriers among various disciplines. However, what is now required is a truly transdisciplinary meta-framework, which would weave the knowledge from existing disciplines into new concepts and methods that could address the many facets of sustainable development – from concept to actual practice. Thus, sustainomics would provide a comprehensive and eclectic knowledge base to support sustainable development efforts – see Figure 1b.

The sustainomics approach encompasses recent initiatives on a 'sustainability transition' and 'sustainability science', and goes even further in seeking to synthesize a 'science of sustainable development', which integrates knowledge from both the sustainability and development domains (Clark, 2000; Parris and Kates, 2001; Tellus Institute, 2001). Such a synthesis will need to draw on core disciplines such as ecology, economics, and sociology, as well as anthropology, botany, chemistry, demography, ethics, geography, law, philosophy, physics, psychology, zoology, etc. Technological skills such as engineering, biotechnology (e.g. to enhance food production), and information technology (e.g. to improve the efficiency of natural resource use), also play a key role. Methods that bridge the economy-society-environment interfaces are especially important. For example, environmental and resource economics attempts to incorporate environmental considerations into traditional neoclassical economic analysis (Freeman, 1993; Teitenberg, 1992). The growing field of ecological economics goes further in combining ecological and economic methods to address environmental problems, and emphasizes the importance of key concepts like the scale of economic activities (for a good introduction, see (Costanza *et al.*, 1997). Newer areas related to ecological science, such as conservation ecology, ecosystem management and political ecology, have led to alternative approaches to the problems of sustainability, including crucial concepts like system resilience, and integrated analysis of ecosystems and human actors (Holling, 1992). Recent papers in sociology have explored ideas about the integrative glue that binds societies together, while drawing attention to the concept of social capital and the importance of social inclusion (Putnam, 1993). The literature on energetics and energy economics has focused on the relevance of physical laws, such as the first and second laws of thermodynamics (covering mass/energy balance and entropy, respectively). This research has yielded valuable insights into how energy flows link physical, ecological and socioeconomic systems together, and analysed the limits placed on ecological and socioeconomic processes by laws governing the transformation of 'more available' (low entropy) to 'less available' (high entropy) energy (Georgescu-Roegen, 1971; Munasinghe, 1990; Hall, 1995). Recent work on sociological economics, environmental sociology, cultural economics, economics of sociology, and sociology of the environment is also relevant. The literature on environmental ethics has explored many issues, including the weights to be attached to values and human motivations, decision-making processes, consequences of decisions, intra- and inter-generational equity, the 'rights' of animals and the rest of nature, and human responsibility for the stewardship of the environment (Andersen, 1993; Environmental Ethics; Sen, 1987; Westra, 1994).

While seeking to build on such earlier work, sustainomics projects a more neutral image. The neologism is necessary to focus attention explicitly on sustainable development, and avoid the implication of any disciplinary bias or hegemony. For example, both biology and sociology can provide important insights into human behaviour, which challenge the 'rational actor' assumptions of neoclassical economics. Thus, recent studies seek to explain phenomena such as hyperbolic discounting (versus the more conventional exponential discounting), reciprocity, and altruistic responses (as opposed to selfish, individualistic behaviour) (Gintis, 2000; Robson, 2001). In the same vein, Siebhuner (2000) has sought to define '*homo sustinens*' as a moral, cooperative individual with social, emotional and nature-related skills, as opposed to the conventional '*homo economicus*' motivated primarily by economic self interest and competitive instincts. The substantive trans-disiplinary framework underlying sustainomics is the precursor of a more rigorous 'science of sustainable development'. The approach should lead to the balanced and consistent treatment of the economic, social and environmental dimensions of sustainable development (as well as other relevant disciplines and paradigms). Balance is also needed in the relative emphasis placed on traditional development versus sustainability. For example, much of the mainstream literature on sustainable development which originates in the North tends to focus on pollution, the unsustainability of growth, and population increase. These ideas have far less resonance in the South, whose priorities include continuing development, consumption and growth, poverty alleviation, and equity.

Many disciplines contribute to the sustainomics framework, while sustainable development itself involves every aspect of human activity, including complex interactions among socioeconomic, ecological and physical systems. The scope of analysis needs to extend from the global to the local scale, cover time spans extending to centuries (for example, in the case of climate change), and deal with problems of uncertainty, irreversibility, and non-linearity. The sustainomics framework seeks to establish an overarching design for analysis and policy guidance, while the constituent components (or disciplines) provide the 'reductionist' building blocks and foundation. The heuristic element underlines the need for continuous rethinking based on new research, empirical findings and current best practice, because reality is more complex than our models, our understanding is incomplete, and we have no consensus on the subject. Furthermore, the precise definition of sustainable development remains an elusive (and perhaps unreachable) goal. Thus, a less ambitious strategy that merely seeks to make development more sustainable might offer greater promise. Such an incremental (or gradient-based) method is more practical, because many unsustainable activities may be easier to recognize and eliminate. In particular, it will help us avoid sudden catastrophic ('cliff edge') outcomes.

This paper identifies some of the key constituent elements of sustainomics and how they might fit together. It also illustrates some of these concepts, by applying them to case studies involving energy problems (the theme of this special issue of *IJSD*) across the full range of spatial scales – at the global-transnational, national-economy, subnational-sectoral, and local-project levels. The current state of knowledge is inadequate to provide a comprehensive definition of sustainomics. Furthermore, sustainomics must provide a heuristic, dynamically evolving framework, in order to address rapidly changing sustainable development issues. Therefore, the intention here is to sketch out several preliminary ideas that would serve as a starting point, thereby stimulating discussion and encouraging further contributions that are needed to flesh out the initial framework.

2 Some elements of sustainomics

Current approaches to sustainable development draw on the experience of several decades of development efforts. Historically, the development of the industrialized world focused on material production. Not surprisingly, most industrialized and developing nations have pursued the economic goal of increasing output and growth during the twentieth century. Thus, the traditional approach to development was strongly associated with economic growth, but has important social dimensions as well (see the section on poverty and equity, below).

By the early 1960s the large and growing numbers of poor in the developing world, and the lack of 'trickle-down' benefits to them, resulted in greater efforts to improve income distribution directly. The development paradigm shifted towards equitable growth, where social (distributional) objectives, especially poverty alleviation, were recognized to be as important as economic efficiency, and distinct from the latter (see the section on poverty and equity, below).

Protection of the environment has now become the third major objective of sustainable development. By the early 1980s, a large body of evidence had accumulated that environmental degradation was a major barrier to development, and new proactive safeguards were introduced (such as the environmental assessments).

Broadly speaking, sustainable development may be described as a process for improving the range of opportunities that will enable individual human beings and communities to achieve their aspirations and full potential over a sustained period of time, while maintaining the resilience of economic, social and environmental systems (Munasinghe 1994). In other words, sustainable development requires increases both in adaptive capacity and in opportunities for improvement of economic, social and ecological systems (Gunderson and Holling 2001). Improving adaptive capacity will increase resilience and sustainability. Expanding the set of opportunities for improvement will give rise to development. Heuristic behaviour of individual organisms and systems facilitates learning, the testing of new processes, adaptation, and improvement. Adapting this general concept, a more focused and practical approach towards making development more sustainable would seek continuing improvements in the present quality of life at a lower intensity of resource use, thereby leaving for future generations an undiminished stock of productive assets (i.e., manufactured, natural and social capital) that will enhance opportunities for improving their quality of life.

2.1 Economic aspects

Economic progress is often evaluated in terms of welfare (or utility) – measured as willingness to pay for goods and services consumed. Thus, many economic policies typically seek to enhance income, and induce more efficient production and consumption of (mainly marketed) goods and services. The stability of prices and employment are among other important objectives. At the same time, the equation of welfare with monetary income and consumption has been challenged for many years. For example, Buddhist philosophy (over 2500 years old) still stresses that contentment is not synonymous with material consumption (Ven. Narada, 1988). More recently, Maslow (1970) and others have identified hierarchies of needs that provide psychic satisfaction, beyond mere goods and services.

The degree of economic efficiency is measured in relation to the ideal of Pareto optimality, which encourages actions that will improve the welfare of at least one individual without worsening the situation of anyone else. The idealized, perfectly competitive economy is an important (Pareto optimal) benchmark, where (efficient) market prices play a key role in both allocating productive resources to maximize output, and ensuring optimal consumption choices which maximize consumer utility. If significant economic distortions are present appropriate shadow prices need to be used. The well known cost-benefit criterion accepts all projects whose net benefits are positive (i.e. aggregate benefits exceed costs) (Munasinghe, 1993). It is based on the weaker 'quasi' Pareto condition, which assumes that such net benefits could be redistributed from the potential gainers to the losers, so that no one is worse off than before. More generally, interpersonal comparisons of (monetized) welfare are fraught with difficulty – both within and across nations, and over time (e.g. the value of human life).

2.1.1 Economic sustainability

The modern concept underlying economic sustainability seeks to maximize the flow of income that could be generated while at least maintaining the stock of assets (or capital) which yield these beneficial outputs (Solow, 1986; Maler, 1990). This approach is based on the pioneering work of Lindahl and Hicks. For example, Hicks (1946) implies that people's maximum sustainable consumption is 'the amount that they can consume without impoverishing themselves'. Much earlier Fisher (1906) had defined *capital* as 'a stock of instruments existing at an instant of time', and *income* as 'a stream of services flowing from this stock of wealth'. Economic efficiency continues to play a key role – in ensuring both efficient allocation of resources in production, and efficient consumption choices that maximize utility. Problems of interpretation arise in identifying the kinds of capital to be maintained (for example, manufactured, natural, and human resource stocks, as well as social capital have been identified) and their substitutability (see next section). Often, it is difficult to value these assets and the services they provide, particularly in the case of ecological and social resources (Munasinghe, 1993). Even key economic assets may be overlooked, for example, in informal or subsistence economies where non-market based transactions are important. The issues of uncertainty, irreversibility and catastrophic collapse pose additional difficulties in determining dynamically efficient development paths (Pearce and Turner, 1990). Many commonly used microeconomic approaches rely heavily on marginal analysis based on small perturbations (e.g. comparing incremental costs and benefits of economic activities). From the viewpoint of resilience theory (discussed below), this type of system soon returns to its dominant stable equilibrium and thus there is little risk of instability. Such methods assume smoothly changing variables and are therefore rather inappropriate for analysing large changes, discontinuous phenomena, and sudden transitions among multiple equilibria. More recent work (especially at the cutting edge of the economics-ecology interface) has begun to explore the behaviour of large, non-linear, dynamic and chaotic systems, as well as newer concepts like system vulnerability and resilience.

2.2 Environmental aspects

Development in the environmental sense is a rather recent concern relating to the need to manage scarce natural resources in a prudent manner – because human welfare ultimately depends on ecological services. Ignoring safe ecological limits will increase the risk of undermining long-run prospects for development. Dasgupta and Maler (1997) point out that until the 1990s, the mainstream development literature hardly mentioned the topic of environment (see for example, Stern, 1989; Chenery and Srinivasan, 1988, 1989; and Dreze and Sen, 1990). An even more recent review paper on economic growth in the well-known *Journal of Economic Literature* mentions the role of natural resources only in the passing (Temple, 1999). Examples of the growing literature on the theme of environment and sustainable development include books by Faucheux *et al.* (1996) describing models of sustainable development, and Munasinghe *et al.* (2001) explicitly addressing the links between growth and environment.

2.2.1 Environmental sustainability

The environmental interpretation of sustainability focuses on the overall viability and health of ecological systems – defined in terms of a comprehensive, multiscale, dynamic, hierarchical measure of resilience, vigour and organization (Costanza, 2000). The classic definition of resilience was provided by Holling (1973) in terms of the ability of an ecosystem to persist despite external shocks. Resilience is determined by the amount of change or disruption that will cause an ecosystem to switch from one system state to another. An ecosystem state is defined by its internal structure and set of mutually re-enforcing processes. Petersen *et al.* (1998) argue that the resilience of a given ecosystem depends on the continuity of related ecological processes at both larger and smaller spatial scales (see Box 1). Further discussion of resilience may be found in Pimm (1991), and Ludwig *et al.* (1997). Vigour is associated with the primary productivity of an ecosystem. It is analogous to output and growth as an indicator of dynamism in an economic system. Organization depends on both complexity and structure in an ecological or biological system. For example, a multicellular organism like a human being is more highly organized (having more diverse subcomponents and interconnections among them), than a single celled amoeba. Higher states of organization imply lower levels of entropy. Thus, the second law of thermodynamics requires that the sustainability of more complex organisms depends on the use of low entropy energy derived from their environment, which is returned as (less useful) high entropy energy. The ultimate source of this energy is solar radiation.

In this context, natural resource degradation, pollution and loss of biodiversity are detrimental because they increase vulnerability, undermine system health, and reduce resilience (Perrings and Opschoor, 1994; Munasinghe and Shearer, 1995). The notion of a safe threshold (and the related concept of carrying capacity) are important – often to avoid catastrophic ecosystem collapse (Holling, 1986). It is useful to also think of sustainability in terms of the normal functioning and longevity of a nested hierarchy of ecological and socioeconomic systems, ordered according to scale – e.g. a human community would consist of many individuals, who are themselves composed of a large number of cells (see Box 1 for details). Gunderson and Holling (2001) use the term ‘panarchy’ to denote such a hierarchy of systems and their adaptive cycles across scales. A system at a given level is able to operate in its stable (sustainable) mode, because it is protected by the slower and more conservative changes in the super-system above it, while being simultaneously invigorated and energized by the faster cycles taking place in the sub-systems below it. In brief, both conservation and continuity from above, and innovation and change from below, are integral to the panarchy-based approach, helping to resolve the apparent paradox between the need for stability as well as change.

Sustainable development is not necessarily synonymous with the maintenance of the ecological *status quo*. From an economic perspective, a coupled ecological-socioeconomic system should evolve so as to maintain a level of biodiversity that will guarantee the resilience of the ecosystems on which human consumption and production depend. Sustainable development demands compensation for the opportunities foregone by future generations, because today's economic activity changes the level or composition of biodiversity in a way that will affect the flow of vital future ecological services, and narrow the options available to unborn generations. This holds true even if positive rates of economic growth indicate an increase in the instrumental (or use) values of options currently available.

Box 1 Spatial and temporal aspects of sustainability

An operationally useful concept of sustainability must refer to the persistence, viability and resilience of organic or biological systems, over their 'normal' lifespan (see the main text for a discussion of resilience). In this ecological context, sustainability is linked with both spatial and temporal scales, as shown in Figure B1. The X axis indicates lifetime in years and the Y axis shows linear size (both in logarithmic scale). The central O represents an individual human being – having a longevity and size of the order of 100 years and 1.5 metres, respectively. The diagonal band shows the expected or 'normal' range of lifespans for a nested hierarchy of living systems (both ecological and social), starting with single cells and culminating in the planetary ecosystem. The bandwidth accommodates the variability in organisms as well as longevity.

Environmental changes that reduce lifespans below the normal range imply that external conditions have made the systems under consideration unsustainable. In short, the regime above and to the left of the normal range denotes premature death or collapse. At the same time, it is unrealistic to expect any system to last forever. Indeed, each sub-system of a larger system (such as single cells within a multi-cellular organism) generally has a shorter lifespan than the larger system itself. If subsystem life spans increase too much, the system above it is likely to lose its plasticity and become 'brittle' – as indicated by the region below and to the right of the normal range (Holling, 1973). In other words, it is the timely death and replacement of subsystems that facilitate successful adaptation, resilience and evolution of larger systems.

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We may argue that sustainability requires biological systems to be able to enjoy a normal life span and function normally, within the range indicated in Figure B1. Thus, leftward movements would be especially undesirable. For example, the horizontal arrow might represent a case of infant death – indicating an unacceptable deterioration in human health and living conditions. In this specific case, extended longevity involving a greater than normal lifespan would not be a matter for particular concern. On the practical side, forecasting up to a timescale of even several hundred years is rather imprecise. Thus, it is important to improve the accuracy of scientific models and data, in order to make very long-term predictions of sustainability (or its absence) more convincing – especially in the context of persuading decision makers to spend large sums of money to reduce unsustainability. One way of dealing with uncertainty, especially if the potential risk is large, relies on a precautionary approach – i.e. avoiding unsustainable behaviour using low cost measures, while studying the issue more carefully.

To conclude, sustainable development of ecological systems requires both adaptive capacity and opportunities for improvement. Improving adaptive capacity will increase resilience and sustainability. Expanding the set of opportunities for system improvement will give rise to development. Heuristic system behaviour facilitates learning, the testing of new processes, adaptation, and improvement.

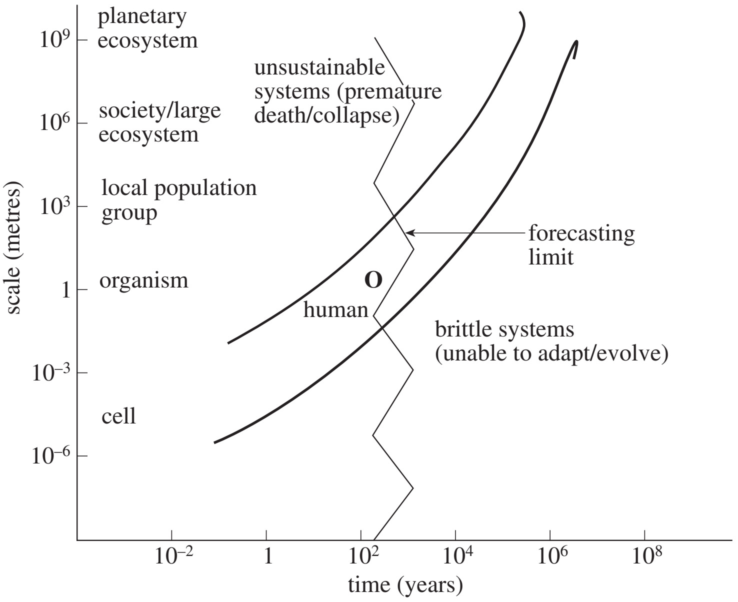


Figure B1 Spatial and temporal norms for sustainable biological and social systems.

2.3 Social aspects

Social development usually refers to improvements in both individual well-being and the overall welfare of society (more broadly defined), that result from increases in social capital – typically, the accumulation of capacity for individuals and groups of people to work together to achieve shared objectives. The institutional component of social capital refers mainly to the formal laws as well as to traditional or informal understandings that govern behaviour, while the organizational component is embodied in the entities (both individuals and social groups) that operate within these institutional arrangements. The quantity and quality of social interactions that underlie human existence, including the level of mutual trust and extent of shared social norms, help to determine the stock of social capital. Thus social capital tends to grow with greater use and erodes through disuse, unlike economic and environmental capital, which are depreciated or depleted by use. Furthermore, some forms of social capital may be harmful (e.g. cooperation within criminal gangs may benefit them, but impose far greater costs on the larger community).

There is an important element of equity and poverty alleviation as well (see below). Thus, the social dimension of development includes protective strategies that reduce vulnerability, improve equity and ensure that basic needs are met. Future social development will require socio-political institutions that can adapt to meet the challenges of modernization – which often destroy traditional coping mechanisms that have evolved in the past (especially to protect disadvantaged groups).

2.3.1 Social sustainability

Social sustainability is able to draw on the ideas discussed earlier regarding environmental sustainability, since habitats may be interpreted broadly to include man-made environments like cities and villages (UNEP, IUCN, and WWF, 1991). Reducing the vulnerability and maintaining the health (i.e. resilience, vigour and organization) of social and cultural systems, and their ability to withstand shocks, is also important (Chambers, 1989; Bohle *et al.*, 1994; Ribot *et al.*, 1996). Enhancing human capital (through education) and strengthening social values and institutions (like trust and behavioural norms) are key aspects. Weakening social values, institutions and equity will reduce the resilience of social systems and undermine governance. Many such harmful changes occur slowly, and their long-term effects are often overlooked in socio-economic analysis. Preserving cultural diversity and cultural capital across the globe, strengthening social cohesion and networks of relationships, and reducing destructive conflicts, are integral elements of this approach. An important aspect of empowerment and broader participation is subsidiarity – i.e. decentralization of decision making to the lowest (or most local) level at which it is still effective. In summary, for both ecological and socioeconomic systems, the emphasis is on improving system health and its dynamic ability to adapt to change across a range of spatial and temporal scales, rather than the conservation of some 'ideal' static state (see also Box 1).

2.4 Equity and poverty

Equity and poverty are two important issues in the sustainomics framework, which have social, economic and environmental dimensions – see Figure 1a. Recent worldwide statistics are compelling. Over 2.8 billion people (almost half the global population) live on less than US$2 per day, and 1.2 billion barely survive on under US$1 per day. The top 20 percentile of the world's population consumes about 83 percent of total output, while the bottom 20 percentile consumes only 1.4 percent. Income disparities are worsening – the per capita ratio between the richest and the poorest 20 percentile groups was 30 to 1 in 1960 and over 80 to 1 by 1995. In poor countries, up to half the children under five years of age are malnourished, whereas the corresponding figure in rich countries is less than 5 percent.

Equity is an ethical and usually people-oriented concept with primarily social, and some economic and environmental dimensions. It focuses on the basic fairness of both the processes and outcomes of decision-making. The equity of any action may be assessed in terms of a number of generic approaches, including parity, proportionality, priority, utilitarianism, and Rawlsian distributive justice. For example, Rawls (1971) stated that 'Justice is the first virtue of social institutions, as truth is of systems of thought'. Societies normally seek to achieve equity by balancing and combining several of these criteria.

Poverty alleviation, improved income distribution and intra-generational (or spatial) equity are key aspects of economic policies seeking to increase overall human welfare (Sen, 1981, 1984). Brown (1998) points out shortcomings in utilitarianism, which underlies much of the economic approach to equity. Broadly speaking, economic efficiency provides guidance on producing and consuming goods and services more efficiently, but is unable to provide a means of choosing (from a social perspective) among various patterns of consumption that are efficient. Equity principles provide better tools for making judgements about such choices.

Social equity is also linked to sustainability, because highly skewed or unfair distributions of income and social benefits are less likely to be acceptable or lasting in the long run. Equity is likely to be strengthened by enhancing pluralism and grass-roots participation in decision-making, as well as by empowering disadvantaged groups (defined by income, gender, ethnicity, religion, caste, etc.) (Rayner and Malone, 1998). In the long term, considerations involving inter-generational equity and safeguarding the rights of future generations are key factors. In particular, the economic discount rate plays a key role with respect to both equity and efficiency aspects (Arrow *et al.*, 1995). Further details of equity-efficiency interactions that need to be reconciled within the sustainomics framework are reviewed in Box 2.

Box 2 Interactions between social equity and economic efficiency

Conflicts between economic efficiency and equity may arise due to assumptions about the definition, comparison and aggregation of the welfare of different individuals or nations. For example, efficiency often implies maximization of output subject to resource constraints. The common assumption is that increases in average income *per capita* will make most or all individuals better off. However, this approach can potentially result in a less equitable income distribution. Overall welfare could drop depending on how welfare is defined in relation to the distribution of income. Conversely, total welfare might increase if policies and institutions can ensure appropriate resource transfers – typically from the rich to the poor.

In the same context, aggregating and comparing welfare across different countries is a disputable issue. Gross National Product (GNP) is simply a measure of the total measurable economic output of a country, and does not represent welfare directly. Aggregating GNP across nations is not necessarily a valid measure of global welfare. However, national economic policies frequently focus more on the growth of GNP rather than its distribution, indirectly implying that additional wealth is equally valuable to rich and poor alike, or that there are mechanisms to redistribute wealth in a way that satisfies equity goals. Attempts have been made to incorporate equity considerations within a purely economic framework, by the weighting of costs and benefits so as to give preference to the poor. Although systematic procedures exist for determining such weights, often the element of arbitrariness in assigning weights has caused many practical problems.

At the same time, it should be recognized that all decision-making procedures do assign weights (arbitrarily or otherwise). For example, progressive personal income taxes are designed to take proportionately more from the rich. On the other hand, traditional cost-benefit analysis based on economic efficiency (which seeks to maximize net benefits) assigns the same weight of unity to all monetary costs and benefits – irrespective of income levels. More pragmatically, in most countries the tension between economic efficiency and equity is resolved by keeping the two approaches separate, e.g. by maintaining a balance between maximizing GNP, and establishing institutions and processes charged with redistribution, social protection, and provision of various social goods to meet basic needs. The interplay of equity and efficiency at the international level is illustrated later, in the climate change case study.

Equity in the environmental sense has received more attention recently, because of the disproportionately greater environmental damages suffered by disadvantaged groups. In the same vein, poverty alleviation efforts (which traditionally focused on raising monetary incomes), are being broadened to address the degraded environmental and social conditions facing the poor.

In summary, both equity and poverty have not only economic but also social and environmental dimensions and, therefore, they need to be assessed using a comprehensive set of indicators (rather than income distribution alone). From an economic policy perspective, emphasis needs to be placed on expanding employment and gainful opportunities for poor people through growth, improving access to markets, and increasing both assets and education. Social policies would focus on empowerment and inclusion, by making institutions more responsive to the poor, and removing barriers that exclude disadvantaged groups. Environmentally related measures to help poor people might seek to reduce their vulnerability to disasters and extreme weather events, crop failures, loss of employment, sickness, economic shocks, etc. Thus, an important objective of poverty alleviation is to provide poor people with assets (e.g. enhanced physical, human and financial resources) that will reduce their vulnerability. Such assets increase the capacity for both coping (i.e. making short-run changes) and adapting (i.e. making permanent adjustments) to external shocks (Moser, 1998). The foregoing ideas merge quite naturally with the sustainable livelihoods approach, which focuses on access to portfolios of assets (social, natural and manufactured), the capacity to withstand shocks, gainful employment, and social processes, within a community or individual oriented context.

An even broader non-anthropocentric approach to equity involves the concept of fairness in the treatment of non-human forms of life or even inanimate nature. One view asserts that humans have the responsibility of prudent ‘stewardship’ (or ‘trusteeship’) over nature, which goes beyond mere rights of usage (see for example, Brown, 1998).

2.5 *Integration of economic, social and environmental considerations*

As a prelude to integration, it is useful to compare the concepts of ecological, social and economic sustainability. One useful idea is that of the maintenance of the set of opportunities, as opposed to the preservation of the value of the asset base (Githinji and Perrings, 1992). In fact, if preferences and technology vary through successive generations, merely preserving a constant value of the asset base becomes less meaningful. By concentrating on the size of the opportunity set, the importance of biodiversity conservation becomes more evident, for the sustainability of an ecosystem. The preservation of biodiversity allows the system to retain resilience by protecting it from external shocks, in the same manner that preservation of the capital stock protects economic assets for future consumption. Differences emerge because under the Hicks-Lindahl income measure, a society that consumes its fixed capital without replacement is not sustainable, whereas using an ecological approach, loss of resilience implies a reduction in the self-organization of the system, but not necessarily a loss in productivity. In the case of social systems, resilience depends to a certain extent on the capacity of human societies to adapt and continue functioning in the face of stress and shocks. Thus, linkages between socio-cultural and ecological sustainability emerge through the organizational similarities between human societies and ecological systems, and the parallels between biodiversity and cultural diversity. From a longer term perspective, the concept of co-evolution of social, economic and ecological systems, within a larger, more complex adaptive system, provides useful insights regarding the harmonious integration of the various elements of sustainable development – see Figure 1a (Munasinghe, 1994; Costanza, 1997).

One may conclude that the exact definition of sustainable development paths is likely to be extremely difficult at this stage, and may be considered a long-run or ideal objective. However, a more promising and practical shorter run goal that is consistent with the sustainomics approach, is to seek strategies that might make future development prospects more sustainable. In such an approach, one key step would be to begin by eliminating the many unsustainable activities that are readily identifiable.

It is important to integrate and reconcile the economic, social and environmental aspects within a holistic and balanced sustainable development framework. Economic analysis has a special role in contemporary national policy making, since some of the most important decisions fall within the economic domain. While mainstream economics which is used for practical policy making has often ignored many crucial aspects of the environmental and social dimensions of sustainable development, there is a small but growing body of literature which seeks to address such shortcomings – see for example, recent issues of the journals *Ecological Economics* and *Conservation Ecology* (published on the internet).

Two broad approaches are relevant for integrating the economic, social and environmental dimensions of sustainable development. They are distinguished by the degree to which the concepts of *optimality* and *durability* are emphasized. While there are overlaps between the two approaches, the main thrust is somewhat different in each case. Uncertainty often plays a key role in determining which approach would be preferred. For example, relatively steady and well-ordered conditions may encourage optimizing behaviour that attempts to control and even fine-tune outcomes, whereas a subsistence farmer facing chaotic and unpredictable circumstances might opt for a more durable response that simply enhances survival prospects.

2.6 Optimality

The optimality-based approach has been widely used in economic analysis to generally maximize welfare (or utility), subject to the requirement that the stock of productive assets (or welfare itself) is non-decreasing in the long term This assumption is common to most sustainable economic growth models – for useful reviews, see Pezzey (1992) and Islam (2001). The essence of the approach is illustrated by the simple example of maximization of the flow of aggregate welfare (W), cumulatively discounted over infinite time (t), as represented by the expression:

$$\max \int_0^\infty W(C, Z)\mathrm{e}^{-rt}\,\mathrm{d}t$$

Here, C represents the consumption rate, Z is a set of other relevant variables, and r is the discount rate. Side constraints might be imposed to satisfy sustainability requirements – e.g. non-decreasing stocks of productive assets (including natural resources).

Some ecological models also optimize variables such as energy use, nutrient flow, or biomass production – giving more weight to system vigour as a measure of sustainability. In economic models, utility is often measured mainly in terms of the net benefits of economic activities, i.e. the benefits derived from development activities minus the costs incurred to carry out those actions (for more details about valuation, see Box 3 below, and Munasinghe, 1993, or Freeman, 1993). More sophisticated economic optimization approaches seek to include environmental and social variables (e.g. by attempting to value environmental externalities, system resilience, etc.). However, given the difficulties of quantifying and valuing many such 'non-economic' assets, the costs and benefits associated with market-based activities tend to dominate in most economic optimization models.

Basically, the optimal growth path maximizes economic output, while the sustainability requirement is met (within this framework) by ensuring non-decreasing stocks of assets (or capital). Some analysts support a 'strong sustainability' constraint, which requires the separate preservation of each category of critical asset (for example, manufactured, natural, socio-cultural and human capital), assuming that they are complements rather than substitutes. One version of this rule might correspond roughly to maximizing economic output, subject to side constraints on environmental and social variables that are deemed critical for sustainability (e.g. biodiversity loss or meeting the basic needs of the poor). Other researchers have argued in favour of 'weak sustainability', which seeks to maintain the aggregate monetary value of the total stock of assets, assuming that the various asset types may be valued and that there is some degree of substitutability among them (see for example, Nordhaus and Tobin, 1972).

Side constraints are often necessary because the underlying basis of economic valuation, optimization and efficient use of resources may not be easily applied to ecological objectives, such as protecting biodiversity and improving resilience, or to social goals, such as promoting equity, public participation and empowerment. Thus, such environmental and social variables cannot be easily combined into a single valued objective function with other measures of economic costs and benefits (see sections on cost-benefit and multi-criteria analysis, below). Moreover, the price system (which has time lags) might fail to anticipate reliably irreversible environmental and social harm, and non-linear system responses that could lead to catastrophic collapse. In such cases, non-economic indicators of environmental and social status would be helpful – e.g. area under forest cover, and incidence of conflict (see for example, Munasinghe and Shearer, 1995; Hanna and Munasinghe, 1995; UNDP, 1998; World Bank, 1998). The constraints on critical environmental and social indicators are proxies representing safe thresholds, which help to maintain the viability of those systems. In this context, techniques like multicriteria analysis may be required, to facilitate trade-offs among a variety of non-commensurable variables and objectives (see for example, Meier and Munasinghe, 1994). Risk and uncertainty will also necessitate the use of decision analysis tools (for a concise review of climate change decision-making frameworks, see Toth, 1999). Recent work has underlined the social dimension of decision science, by pointing out that risk perceptions are subjective and depend on the risk measures used, as well as other factors such as ethno-cultural background, socio-economic status, and gender (Bennet, 2000).

2.7 Durability

The second broad integrative approach would focus primarily on sustaining the quality of life – e.g. by satisfying environmental, social and economic sustainability requirements. Such a framework favours 'durable' development paths that permit growth, but are not necessarily economically optimal. There is more willingness to trade off some economic optimality for the sake of greater safety, in order to stay within critical environmental and social limits – especially among increasingly risk-averse and vulnerable societies or individuals who face chaotic and unpredictable conditions (see the discussion on the precautionary principle in Section 3.1). The economic constraint might be framed in terms of maintaining consumption levels (defined broadly to include environmental services, leisure and other 'non-economic' benefits) – i.e. *per capita* consumption that never falls below some minimum level, or is non-declining. The environmental and social sustainability requirements may be expressed in terms of indicators of 'state' that seek to measure the durability or health (resilience, vigour and organization) of complex ecological and socio-economic systems. As an illustrative example, consider a simple durability index (D) for an ecosystem measured in terms of its expected lifespan (in a healthy state), as a fraction of the normal lifespan (see also Box 1). We might specify: $D = D(R,V,O,S)$, to indicate the dependence of durability on resilience (R), vigour (V), organization (O), and the state of the external environment (S) – especially in relation to potentially damaging shocks. There is the likelihood of further interaction here, owing to linkages between the sustainability of social and ecological systems – e.g. social disruption and conflict could exacerbate damage to ecosystems, and *vice versa*. For example, long-standing social norms in many traditional societies have helped to protect the environment (Colding and Folke, 1997).

Durability encourages a holistic systemic viewpoint, which is important in sustainomics analysis. The self-organizing and internal structure of ecological and socioeconomic systems makes 'the whole more durable (and valuable) than the sum of the parts'. A narrow definition of efficiency based on marginal analysis of individual components may be misleading (Schutz, 1999). For example, it is more difficult to value the integrated functional diversity in a forest ecosystem than the individual species of trees and animals. Therefore, the former is more likely to fall victim to market failure (as an externality). Furthermore, even where correct environmental shadow prices prevail, some analysts point out that cost minimization could lead to homogenization and consequent reductions in system diversity (Daly and Cobb, 1989; Perrings *et al.*, 1995). Systems analysis also helps to identify the benefits of cooperative structures and behaviour, which a more partial analysis may neglect.

The possibility of many durable paths favours simulation-based methods, including consideration of alternative world views and futures (rather than one optimal result). This approach is consonant with recent research on integrating human actors into ecological models (*Ecological Economics*, 2000). Key elements include multiple-agent modelling to account for heterogeneous behaviour, recognition of bounded rationality leading to different perceptions and biases, and more emphasis on social interactions that give rise to responses like imitation, reciprocity and comparison.

In the durability approach, constraints based on sustainability could be represented also by the approach discussed earlier, which focuses on maintaining stocks of assets. Here, the various forms of capital are viewed as a bulwark that decreases vulnerability to external shocks and reduces irreversible harm, rather than mere accumulations of assets that produce economic outputs. System resilience, vigour, organization and ability to adapt will depend dynamically on the capital endowment as well as the magnitude and rate of change of a shock.

2.8 Indicators

In view of the importance of asset stocks to both the optimal and durable approaches, the practical implementation of sustainomics principles will require the identification of specific economic, social and environmental indicators, at different levels of aggregation ranging from the global/macro to local/micro, that are relevant. It is important that the indicators be comprehensive in scope, multi-dimensional in nature (where appropriate), and account for spatial differences. A wide variety of indicators are described already in the literature (Munasinghe and Shearer, 1995; UNDP, 1998; World Bank, 1998; Liverman *et al.*, 1988; Kuik and Verbruggen, 1991; Opschoor and Reijnders, 1991; Holmberg and Karlsson, 1992; Adriaanse, 1993; Alfsen and Saebo, 1993; Bergstrom, 1993; Gilbert and Feenstra, 1994; Moffat, 1994; OECD, 1994; Azar, 1996; UN, 1996; Commission on Sustainable Development (CSD), 1998; World Bank, 1997).

Measuring economic, environmental (natural), human and social capital also raises various problems. Manufactured capital may be estimated using conventional neoclassical economic analysis. As described later in the section on cost-benefit analysis, market prices are useful when economic distortions are relatively low, and shadow prices could be applied in cases where market prices are unreliable (e.g. Squire and van der Tak, 1975). Natural capital needs to be quantified first in terms of key physical attributes. Typically, damage to natural capital may be assessed by the level of air pollution (e.g. concentrations of suspended particulate, sulfur dioxide or GHGs), water pollution (e.g. BOD or COD), and land degradation (e.g. soil erosion or deforestation). Then the physical damage could be valued using a variety of techniques based on environmental and resource economics (e.g. Munasinghe, 1993; Freeman, 1993; Teitenberg, 1992). Human resource stocks are often measured in terms of the value of educational levels, productivity and earning potential of individuals. Social capital is the one that is most difficult to assess (Grootaert, 1998). Putnam (1993) described it as ‘horizontal associations’ among people, or social networks and associated behavioural norms and values, which affect the productivity of communities. A somewhat broader view was offered by Coleman (1990), who viewed social capital in terms of social structures, which facilitate the activities of agents in society – this permitted both horizontal and vertical associations (like firms). An even wider definition is implied by the institutional approach espoused by North (1990) and Olson (1982), which includes not only the mainly informal relationships implied by the earlier two views, but also the more formal frameworks provided by governments, political systems, legal and constitutional provisions, etc. Recent work has sought to distinguish between social and political capital (i.e. the networks of power and influence that link individuals and communities to the higher levels of decision-making).

2.9 Complementarity and convergence of optimal and durable approaches

National economic management often provides good examples of how the two approaches complement one another. For example, economy-wide policies involving both fiscal and monetary measures (e.g. taxes, subsidies, interest rates and foreign exchange rates) might be optimized on the basis of quantitative macroeconomic models. Nevertheless, decision-makers inevitably modify these economically 'optimal' policies before implementing them, to take into account other sociopolitical considerations based more on durability (such as protection of the poor, regional factors, etc.), which facilitate governance and stability. The determination of an appropriate target trajectory for future global GHG emissions (and corresponding target GHG concentration) provides another useful illustration of the interplay of the durability and optimality approaches (for details see IPCC, 1996a; Munasinghe, 1998a, and Case Study 1 below).

The practical potential for convergence of the two approaches may be realized in several ways. First, wastes ought to be generated at rates less than or equal to the assimilative capacity of the environment – for example, emissions of greenhouse gases and ozone-depleting substances into the global atmosphere. Second, renewable resources, especially if they are scarce, should be utilized at rates less than or equal to the natural rate of regeneration. Third, non-renewable resource use should be managed in relation to the substitutability between these resources and technological progress. Both wastes and natural resource input use might be minimized by moving from the linear throughput to the closed loop mode. Thus, factory complexes are being designed in clusters – based on the industrial ecology concept – to maximize the circular flow of materials and recycling of wastes among plants. Finally, inter- and intra-generational equity (especially poverty alleviation), pluralistic and consultative decision-making, and enhanced social values and institutions, are important additional aspects that should be considered (at least in the form of safe limits or constraints).

Greenhouse gas mitigation provides an interesting example of how such an integrative framework could help to incorporate climate change response measures within a national sustainable development strategy. The rate of total GHG emissions (G) may be decomposed by means of the following identity:

$$G = (Q/P) \times (Y/Q) \times (G/Y) \times P$$

where (Q/P) is quality of life per capita; (Y/Q) is the material consumption required per unit of quality of life; (G/Y) is the GHG emission per unit of consumption; and P is the population. A high quality of life can be consistent with low total GHG emissions, provided that each of the other three terms on the right-hand side of the identity could be minimized (see also the discussion below on 'tunnelling' and 'leapfrogging'). Reducing (Y/Q) implies 'social decoupling' (or 'dematerialization') whereby satisfaction becomes less dependent on material consumption – through changes in tastes, behaviour and social values. Similarly (G/Y) may be reduced by 'technological decoupling' (or 'decarbonization') that reduces the intensity of GHG emissions in consumption and production. Finally, population growth needs to be reduced, especially where emissions per capita are already high. The linkages between social and technological decoupling need to be explored (see for example, IPCC, 1999). For example, changes in public perceptions and tastes could affect the directions of technological progress, and influence the effectiveness of mitigation and adaptation policies.

Climate change researchers are currently exploring the application of large and complex integrated assessment models or IAMs, which contain coupled submodels that represent a variety of ecological, geophysical and socioeconomic systems (IPCC, 1997). There is considerable scope to examine how both the optimality and durability approaches might be applied in a consistent manner to the various submodels within an IAM, where appropriate.

2.10 Cost-benefit analysis (CBA)

Cost-benefit analysis (CBA) is one well-known example of a single-valued approach, which seeks to assign economic values to the various consequences of an economic activity. The resulting costs and benefits are combined into a single decision-making criterion, such as the net present value (NPV), internal rate of return (IRR), or benefit-cost ratio (BCR). The basic criterion for accepting a project is that the net present value (NPV) of benefits is positive. Typically, NPV = PVB – PVC, where

$$\mathrm{PVB} = \sum_{\mathrm{t}=0}^{\mathrm{T}} B_t / (1+r)^t$$

$$\mathrm{PVC} = \sum_{\mathrm{t}=0}^{\mathrm{T}} C_t / (1+r)^t$$

B_t and C_t are the project benefits and costs in year t, r is the discount rate, and T is the time horizon. Both benefits and costs are defined as the difference between what would occur *with and without* the project being implemented.

When two projects are compared, the one with the higher NPV is deemed superior. Furthermore, if both projects yield the same benefits (PVB), then it is possible to derive the least cost criterion – where the project with the lower PVC is preferred. The IRR is defined as that value of the discount rate for which PVB = PVC, whereas BCR = PVB/PVC. Further details of these criteria, as well as their relative merits in the context of sustainable development, are provided in Munasinghe, 1993.

If a purely financial analysis is required from the private entrepreneurs viewpoint, then B, C, and r are defined in terms of market or financial prices, and NPV yields the discounted monetary profit. This situation corresponds to the economist's ideal world of perfect competition, where numerous profit-maximizing producers and utility-maximizing consumers achieve a Pareto-optimal outcome. However, conditions in the real world are far from perfect, owing to monopoly practices, externalities (such as environmental impacts which are not internalized in the private market), and interference in the market process (e.g. taxes). Such distortions cause market (or financial) prices for goods and services to diverge from their economically efficient values. Therefore, the economic efficiency viewpoint usually requires that shadow prices (or opportunity costs) be used to measure B, C and r. In simple terms, the shadow price of a given scarce economic resource is given by the change in value of economic output caused by a unit change in the availability of that resource. In practice, there are many techniques for measuring shadow prices – e.g. removing taxes, duties and subsidies from market prices (for details, see Munasinghe, 1993; Squire and van der Tak, 1975).

	Conventional market	Implicit market	Constructed market
Actual behaviour	Effect on production	Travel cost	Artificial market
	Effect on health	Wage differences	
	Defensive or preventive costs	Property values	
		Proxy marketed goods	
Intended behaviour	Replacement cost		Contingent valuation
	Shadow project		

The incorporation of environmental considerations into the economist’s single-valued CBA criterion requires further adjustments. All significant environmental impacts and externalities need to be valued as economic benefits and costs. As explained earlier in the section on indicators, environmental assets may be quantified in physical or biological units. Recent techniques for economically valuing environmental impacts are summarized in Box 3. However, many of them (such as biodiversity) cannot be accurately valued in monetary terms, despite the progress that has been made in recent years (Munasinghe, 1993; Freeman, 1993). Therefore, criteria like NPV often fail to adequately represent the environmental aspect of sustainable development.

Box 3 Recent techniques for economically valuing environmental impacts (Source: Munasinghe, 1993).

Effect on production. An investment decision often has environmental impacts, which in turn affect the quantity, quality or production costs of a range of productive outputs that may be valued readily in economic terms.

Effect on health. This approach is based on health impacts caused by pollution and environmental degradation. One practical measure related to the effect on production is the value of human output lost due to ill health or premature death. The loss of potential net earnings (called the human capital technique) is one proxy for foregone output, to which the costs of health care or prevention may be added.

Defensive or preventive costs. Often, costs may be incurred to mitigate the damage caused by an adverse environmental impact. For example, if the drinking water is polluted, extra purification may be needed. Then, such additional defensive or preventive expenditures (ex-post) could be taken as a minimum estimate of the benefits of mitigation.

Replacement cost and shadow project. If an environmental resource that has been impaired is likely to be replaced in the future by another asset that provides equivalent services, then the costs of replacement may be used as a proxy for the environmental damage – assuming that the benefits from the original resource are at least as valuable as the replacement expenses. A shadow project is usually designed specifically to offset the environmental damage caused by another project. For example, if the original project was a dam that inundated some forest land, then the shadow project might involve the replanting of an equivalent area of forest, elsewhere.

Travel cost. This method seeks to determine the demand for a recreational site (e.g. number of visits per year to a park), as a function of variables like price, visitor income, and socio-economic characteristics. The price is usually the sum of entry fees to the site, costs of travel, and opportunity cost of time spent. The consumer surplus associated with the demand curve provides an estimate of the value of the recreational site in question.

Property Value. In areas where relatively competitive markets exist for land, it is possible to decompose real estate prices into components attributable to different characteristics like house and lot size, air and water quality. The marginal willingness to pay (WTP) for improved local environmental quality is reflected in the increased price of housing in cleaner neighborhoods. This method has limited application in developing countries, since it requires a competitive housing market, as well as sophisticated data and tools of statistical analysis.

Wage differences. As in the case of property values, the wage differential method attempts to relate changes in the wage rate to environmental conditions, after accounting for the effects of all factors other than environment (e.g. age, skill level, job responsibility, etc.) that might influence wages.

Proxy marketed goods. This method is useful when an environmental good or service has no readily determined market value, but a close substitute exists which does have a competitively determined price. In such a case, the market price of the substitute may be used as a proxy for the value of the environmental resource.

Artificial market. Such markets are constructed for experimental purposes, to determine consumer WTP for a good or service. For example, a home water purification kit might be marketed at various price levels, or access to a game reserve may be offered on the basis of different admission fees, thereby facilitating the estimation of values.

Contingent valuation. This method puts direct questions to individuals to determine how much they might be willing to pay for an environmental resource, or how much compensation they would be willing to accept if they were deprived of the same resource. The contingent valuation method (CVM) is more effective when the respondents are familiar with the environmental good or service (e.g. water quality) and have adequate information on which to base their preferences. Recent studies indicate that CVM, cautiously and rigorously applied, could provide rough estimates of value that would be helpful in economic decision-making, especially when other valuation methods were unavailable.

Capturing the social dimension of sustainable development within CBA is even more problematic. Some attempts have been made to attach ‘social weights’ to costs and benefits so that the resultant NPV favours poorer groups (see also Box 2). However, such adjustments (or preferential treatment for the poor) are rather arbitrary, and have weak foundations in economic theory. Other key social considerations, such as empowerment and participation, are hardly represented within CBA. In summary, the conventional CBA methodology would tend to favour the market-based economic viewpoint, although environmental and social considerations might be introduced in the form of side constraints.

2.11 Multi-criteria analysis (MCA)

Multi-criteria analysis (MCA) or multi-objective decision-making is particularly useful in situations when a single criterion approach like CBA falls short. In MCA, desirable objectives are specified, usually within a hierarchical structure. The highest level represents the broad overall objectives (for example, improving the quality of life), which are often vaguely stated. However, they can be broken down usually into more operationally relevant and easily measurable lower level objectives (e.g. increased income). Sometimes only proxies are available – e.g. if the objective is to preserve biological diversity in a rainforest, the practically available attribute may be the number of hectares of rainforest remaining. Although value judgments may be required in choosing the proper attribute (especially if proxies are used), actual measurement does not have to be in monetary terms – unlike CBA. More explicit recognition is given to the fact that a variety of objectives and indicators may influence planning decisions.

Figure 2 is a two-dimensional representation of the basic concepts underlying MCA. Consider an electricity supplier, who is evaluating a hydroelectric project that could potentially cause biodiversity loss. Objective Z_1 is the additional project cost required to protect biodiversity, and Z_2 is an index indicating the loss of biodiversity. The points A, B, C and D in the Figure represent alternative projects (e.g. different designs for the dam). In this case, project B is superior to (or dominates) A in terms of both Z_1 and Z_2 – because B exhibits lower costs as well as less bio-diversity loss relative to A. Thus, alternative A may be discarded. However, when we compare B and C, the choice is more complicated since the former is better than the latter with respect to costs but worse with respect to biodiversity loss. Proceeding in this fashion, a trade-off curve (or *locus* of best options) may be defined by all the non-dominated feasible project alternatives such as B, C and D. Such a curve implicitly places both economic and environmental attributes on a more equal footing, in the spirit of sustainomics.

Further ranking of alternatives is not possible without the introduction of value judgments (for an unconstrained problem). Typically, additional information may be provided by a family of equi-preference curves that indicate the way in which the decision-maker or society trades off one objective against the other (see Figure 2). Each such equi-preference curve indicates the *locus* of points along which society is indifferent to the trade-off between the two objectives. The preferred alternative is the one that yields the greatest utility – i.e. at the point of tangency D of the trade-off curve with the best equi-preference curve (i.e. the one closest to the origin).

Because equi-preference curves are usually not measurable, other practical techniques may be used to narrow down the set of feasible choices on the trade-off curve. One approach uses limits on objectives or 'exclusionary screening'. For example, the decision-maker may face an upper bound on costs (i.e. a budgetary constraint), depicted by $C_{\max}$ in Figure 2. Similarly, ecological experts might set a maximum value of biodiversity loss $B_{\max}$ (e.g. a level beyond which the ecosystem suffers catastrophic collapse). These two constraints may be interpreted in the context of durability considerations, mentioned earlier. Thus, exceeding $C_{\max}$ is likely to threaten the viability of the electricity supplier, with ensuing social and economic consequences (e.g. jobs, incomes, returns to investors etc.). Similarly, violating the biodiversity constraint will undermine the resilience and sustainability of the forest ecolosystem. In a more practical sense, $C_{\max}$ and $B_{\max}$ help to define a more restricted portion of the trade-off curve (darker line) – thereby narrowing and simplifying the choices available to the single alternative D, in Figure 2. This type of analysis may be expanded to include other dimensions and attributes. For example, in our hydroelectric dam case, the number of people displaced (or resettled) could be represented by another social variable Z_3

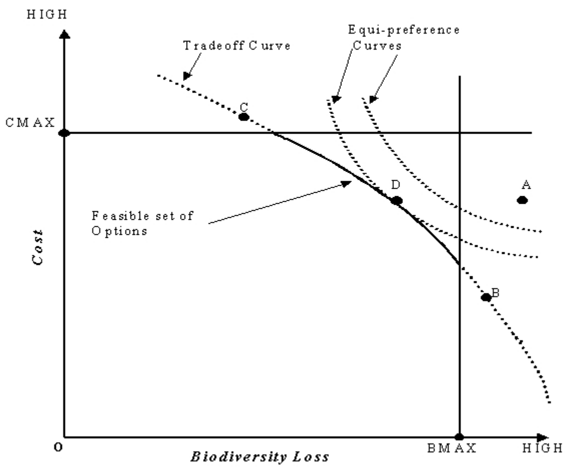
2.12 Restructuring development and growth for greater sustainability

Growth is a major objective of almost all developing countries – especially the poorest ones. This promise cannot be fulfilled unless economic growth is sustained into the long term. The developing countries need to ensure that their endowments of natural resources are not taken for granted and squandered. If valuable resources such as air, forests, soil, and water are not protected, development is unlikely to be sustainable – not just for a few years, but for many decades. Furthermore, on the social side, it is imperative to reduce poverty, create employment, improve human skills and strengthen our institutions.

Next, let us examine the alternative growth paths available, and the role of sustainomics principles in choosing options. Lovelock (1975) made a pioneering contribution with his Gaia hypothesis. He proposed that the totality of life on Earth might be considered an integrated web which works to create a favourable environment for survival. As a corollary, unregulated expansion of human activity might threaten the natural balance. In this spirit, Figure 3a shows how the socioeconomic subsystem (solid rectangle) has always been embedded in a broader ecological system (large oval). National economies are inextricably linked to, and dependent on natural resources –

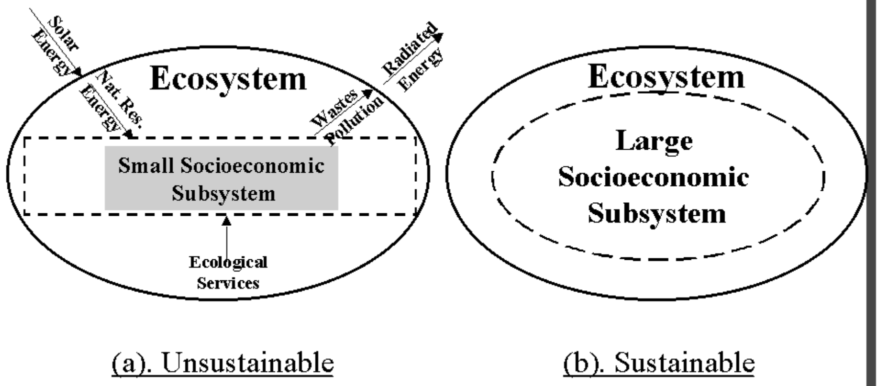
since everyday goods and services are in fact derived from natural resources inputs that originate from the larger ecological system. We extract oil from the ground and timber from trees, and we freely use water and air. At the same time, such activities have continued to expel polluting waste into the environment, quite liberally. The broken line in Figure 3a symbolically shows that in many cases, the scale of human activity has increased to the point where it is now impinging on the underlying ecosystem. This is evident today, if we consider that forests are disappearing, water resources are being polluted, soils are being degraded, and even the global atmosphere is under threat. Consequently, the critical question involves how human society might contain or manage this problem?

Figure 2. Simple Two-Dimensional Example of Multi-criteria Analysis.



One traditional view that has caused confusion among leaders around the world is the assumption that concern for the environment is not necessarily good for economic activity. Thus, until recently the conventional wisdom held that it was not possible to have economic growth and a good environment at the same time, because they were mutually incompatible goals. However, the more modern viewpoint (embodied also in sustainomics), indicates that growth and environment are indeed complements. One key underlying assumption is that it is often possible to devise so-called ‘win-win’ policies, which lead to economic as well as environmental gains (Munasinghe *et al.*, 2001). As illustrated earlier in Figure 3a, the traditional approach to development would certainly lead to a situation where the economic system would impinge upon the boundaries of the ecosystem in a harmful manner. On the other hand, Figure 3b summarizes the modern approach that would allow us to have the same level of prosperity without severely damaging the environment. In this case, the oval outer curve is matched by an oval inner curve – where economic activities have been restructured in a way that is more harmonious with the ecosystem.

Figure 3. Restructuring development to make the embedded socioeconomic subsystem more sustainable within the larger ecosystem.



(a). Unsustainable

(b). Sustainable

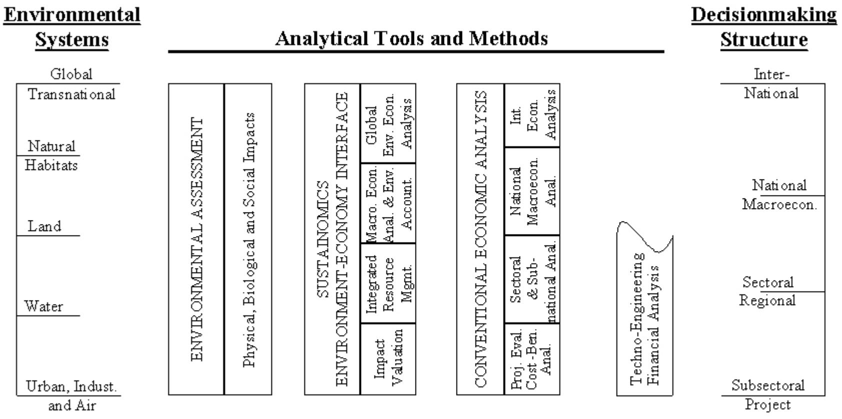
It would be fruitful to seek specific interventions that might help to make the crucial change in mindset, where the emphasis would be on the structure of development, rather than the magnitude of growth (conventionally measured). Policies that promote environmentally- and socially-friendly technologies that use natural resource inputs more frugally and efficiently, reduce polluting emissions, and facilitate public participation in decision-making, are important. One example is the information technology (IT) revolution, which might facilitate desirable restructuring from an environmental perspective, by making modern economies more services oriented, and shifting activities away from highly polluting and material intensive types of manufacturing and extractive industries (Munasinghe, 1994, 1989). If properly managed, IT could also make development more socially sustainable, by improving access to information, increasing public participation in decision-making, and empowering disadvantaged groups. The correct blend of market forces and regulatory safeguards are required.

2.13 Linking sustainable development issues with conventional decision-making

Sustainomics helps in identifying practical economic, social and natural resource management options that facilitate sustainable development. It serves as an essential bridge between the traditional techniques of (economic) decision-making and modern environmental and social analysis. In this context, sustainable development assessment (SDA) is an important tool to ensure balanced analysis of both development and sustainability concerns. The ‘economic’ component of SDA is based on conventional economic and financial analysis (including cost benefit analysis), as described earlier. The other two key components are environmental and social assessment (EA and SA) – see for example World Bank (1998). Poverty assessment is often interwoven with SDA. Economic, environmental and social analyses need to be integrated and harmonized within SDA. Since traditional decision making relies heavily on economics, a first step towards such an integration would be the systematic incorporation of environmental and social concerns into the policy framework of human society.

Figure 4 provides an example of how environmental assessment is combined with economic analysis. The right-hand side of the diagram indicates the hierarchical nature of conventional decision-making in a modern society. The global and transnational level consists of sovereign nation states. In the next level are individual countries, each having a multisectored macroeconomy. Various economic sectors (like industry and agriculture) exist in each country. Finally, each sector consists of different subsectors and projects. The usual decision making process on the right side of Figure 4 relies on techno-engineering, financial and economic analyses of projects and policies. In particular, conventional economic analysis has been well developed in the past, and uses techniques such as project evaluation/cost-benefit analysis (CBA), sectoral/regional studies, multisectoral macroeconomic analysis, and international economic analysis (finance, trade, etc.) at the various hierarchic levels.

Figure 4. Incorporating Environmental Concerns Into Decisionmaking



Unfortunately, environmental and social analysis cannot be carried out readily using the above decision-making structure. We examine how environmental issues might be incorporated into this framework (with the understanding that similar arguments may be made with regard to social issues). The left side of Figure 4 shows one convenient environmental breakdown in which the issues are:

- global and transnational (e.g. climate change, ozone layer depletion);
- natural habitats (e.g. forests and other ecosystems);
- land (e.g. agricultural zone);
- water resource (e.g. river basin, aquifer, watershed);
- urban-industrial (e.g. metropolitan area, airshed).

In each case, a holistic environmental analysis would seek to study a physical or ecological system in its entirety. Complications arise when such natural systems cut across the structure of human society. For example, a large and complex forest ecosystem (like the Amazon) could span several countries, and also interact with many economic sectors within each country.

The causes of environmental degradation arise from human activity (ignoring natural disasters and other events of non-human origin), and therefore, we begin on the right side of the Figure. The ecological effects of economic decisions must then be traced through to the left side. The techniques of environmental assessment (EA) have been developed to facilitate this difficult analysis (World Bank, 1998). For example, destruction of a primary moist tropical forest may be caused by hydroelectric dams (energy sector policy), roads (transport sector policy), slash and burn farming (agriculture sector policy), mining of minerals (industrial sector policy), land clearing encouraged by land-tax incentives (fiscal policy), and so on. Disentangling and prioritizing these multiple causes (right side) and their impacts (left side) will involve a complex analysis.

Figure 4 also shows how sustainomics could play its bridging role at the ecology-economy interface, by mapping the EA results (measured in physical or ecological units) onto the framework of conventional economic analysis. A variety of environmental economic techniques including valuation of environmental impacts (at the local/project level), integrated resource management (at the sector/regional level), environmental macroeconomic analysis and environmental accounting (at the economy level), and global/transnational environmental economic analysis (at the international level), facilitate this process of incorporating environmental issues into traditional decision making. Since there is considerable overlap among the analytical techniques described above, this conceptual categorization should not be interpreted too rigidly. Furthermore, when economic valuation of environmental impacts is difficult, techniques such as multi-criteria analysis (MCA) would be useful (see Figure 2 and earlier discussion on MCA).

Once the foregoing steps are completed, projects and policies must be redesigned to reduce their environmental impacts and shift the development process towards a more sustainable path. Clearly, the formulation and implementation of such policies is itself a difficult task. In the deforestation example described earlier, protecting this ecosystem is likely to raise problems of coordinating policies in a large number of disparate and (usually) non-cooperating ministries and line institutions (i.e. energy, transport, agriculture, industry, finance, forestry, etc.).

Analogous reasoning may be readily applied to social assessment (SA) at the society-economy interface, in order to incorporate social considerations more effectively into the conventional economic decision making framework. In this case, the left side of Figure 4 would include key elements of SA, such as asset distribution, inclusion, cultural considerations, values and institutions. Impacts on human society (i.e. beliefs, values, knowledge and activities), and on the biogeophysical environment (i.e. both living and non-living resources), are often linked via second and higher order paths, requiring integrated application of SA and EA. This insight reflects current thinking on the co-evolution of socio-economic and ecological systems.

In the framework of the figure, the right side represents a variety of institutional mechanisms (ranging from local to global) which would help to implement policies, measures and management practices to achieve a more sustainable outcome. Implementation of sustainable development strategies and good governance would benefit from the transdisciplinary approach advocated in sustainomics. For example, economic theory emphasises the importance of pricing policy to provide incentives that will influence rational consumer behaviour. However, cases of seemingly irrational or perverse behaviour abound, which might be better understood through findings in areas like behavioural and social psychology, and market research. Such work has identified basic principles that help to influence society and modify human actions, including reciprocity (or repaying favours), behaving consistently, following the lead of others, responding to those we like, obeying legitimate authorities, and valuing scarce resources (Cialdini, 2001).

3 Applying the sustainomics framework

In this section, practical case studies are presented which illustrate the application of sustainomics principles to make development sustainable at the global-transnational, national, sub-national and local-project scales.

3.1 Global-transnational scale: climate change

The climate change problem fits readily within the broad conceptual framework of sustainomics, described above. Decision-makers are beginning to show more interest in the assessment of how serious a threat climate change poses to the future basis for improving human welfare (Munasinghe, 2000; Munasinghe and Swart, 2000). For example, increased GHG emissions and other unsustainable practices are likely to undermine the security of nations and communities, through economic, social and environmental impoverishment, as well as inequitable distribution of adverse impacts – with undesirable consequences such as large numbers of ‘environmental’ refugees (Lonergan, 1993; Ruitenbeek, 1996; Westing, 1992). Some of the potential linkages, and the sustainomics-related principles and concepts that apply in this context, are outlined below.

3.1.1 Economic, social and environmental risks

First, global warming poses a significant potential threat to the future economic well-being of large numbers of human beings. In its simplest form, the economic efficiency viewpoint will seek to maximize the net benefits (or outputs of goods and services) from the use of the global resource represented by the atmosphere. Broadly speaking, this implies that the stock of atmospheric assets, which provide a sink function for GHGs, needs to be maintained at an optimum level. As indicated in the case study below, this target level is defined at the point where the marginal GHG abatement costs are equal to the marginal avoided damages. The underlying principles are based on optimality and the economically efficient use of a scarce resource, i.e. the global atmosphere.

Second, climate change could also undermine social welfare and equity in an unprecedented manner. In particular, more attention needs to be paid to the vulnerability of social values and institutions, which are already stressed due to rapid technological changes (Adger, 1999). Especially within developing countries, erosion of social capital is undermining the basic glue that binds communities together – e.g. the rules and arrangements that align individual behaviour with collective goals (Banuri *et al.*, 1994). Existing international mechanisms and systems to deal with transnational and global problems are fragile, and unlikely to be able to cope with worsening climate change impacts.

Furthermore, both intra- and inter-generational equity are likely to be worsened (IPCC, 1996a). Existing evidence clearly demonstrates that poorer nations and disadvantaged groups within nations are especially vulnerable to disasters (Clarke and Munasinghe, 1995; Banuri, 1998). Climate change is likely to result in inequities due to the uneven distribution of the costs of damage, as well as of necessary adaptation and mitigation efforts – such differential effects could occur both among and within countries. Although relevant information is unavailable on global-scale phenomena such as climate change, some historical evidence based on large-scale disasters like El Nino provide useful insights.

Two catastrophic famines or holocausts during the late 19th century killed tens of millions in the developing world. Recent research indicates that they were the outcome of negative synergies between adverse global environmental factors (i.e., the El Nino droughts of 1876-78 and 1898-1901), and the inadequate response of socio-economic systems (i.e. vulnerability of tropical farming forcibly integrated into world commodity markets). In the 18th century, the quality of life in countries like Brazil, China, and India was at least on a par with European standards. However, colonial dictates and rapid expansion of world trade re-oriented production in developing countries to service distant European markets. By the time the El Nino droughts struck in the 19th century, the domination of commodity and financial markets by Britain forced developing country smallholders to export at ever-deteriorating terms of trade. This process undermined local food security, impoverished large populations, and culminated in holocausts on an unprecedented scale – identified as one major cause of the present state of underdevelopment in the Third World. From a sustainomics perspective, the corollary is clear, based on the precautionary principle (see next section). The future vulnerability of developing country food production systems to a combination of climate change impacts and accelerated globalization of commodity and financial markets, poses significant risks to the survival of billions, especially in the poorest nations.

Inequitable distributions are not only ethically unappealing, but also may be unsustainable in the long run (Burton, 1997). For example, a future scenario that restricts *per capita* carbon emissions in the South to 0.5 tonnes per year while permitting a corresponding level in the North of over three tonnes per year will not facilitate the cooperation of developing countries, and therefore is unlikely to be durable. More generally, inequity could undermine social cohesion and exacerbate conflicts over scarce resources.

Third, the environmental viewpoint draws attention to the fact that increasing anthropogenic emissions and accumulations of GHGs might significantly perturb a critical global subsystem – the atmosphere (UNFCCC, 1993). Environmental sustainability will depend on several factors, including:

- climate change intensity (e.g. magnitude and frequency of shocks);
- system vulnerability (e.g. extent of impact damage);
- system resilience (i.e. ability to recover from impacts).

Changes in the global climate (e.g. mean temperature, precipitation, etc.) could also threaten the stability of a range of critical, interlinked physical, ecological and social systems and subsystems (IPCC, 1996b).

3.1.2 Relevant principles for policy formulation

When considering climate change response options, several principles and ideas that are widely used in environmental economics analysis would be useful – these include the polluter pays principle, economic valuation, internalization of externalities, and property rights. The polluter pays principle argues that those who are responsible for damaging emissions should pay the corresponding costs. The economic rationale is that this provides an incentive for polluters to reduce their emissions to optimal (i.e. economically efficient) levels. Here, the idea of economic valuation becomes crucial. Quantification and economic valuation of potential damage from polluting emissions is an important prerequisite. In the case of a common property resource like the atmosphere, GHG emitters can freely pollute without penalties. Such 'externalities' need to be internalized by imposing costs on polluters that reflect the damage caused. An externality occurs when the welfare of one party is affected by the activity of another party who does not take these repercussions into account in his/her decision-making (e.g. no compensating payments are made). The theoretical basis for this is well known since Pigou (1932) originally defined and treated externalities in rigorous fashion. In this context, the notion of property rights is also relevant to establish that the atmosphere is a valuable and scarce resource that cannot be used freely and indiscriminately.

An important social principle is that climate change should not be allowed to worsen existing inequities – although climate change policy cannot be expected to address all prevailing equity issues. Some special aspects include:

- the establishment of an equitable and participative global framework for making and implementing collective decisions about climate change;
- reducing the potential for social disruption and conflicts arising from climate change impacts;
- protection of threatened cultures and preservation of cultural diversity.

From the social equity viewpoint, the polluter pays principle is based not only on economic efficiency, but also on fairness. An extension of this idea is the principle of recompensing victims – ideally by using the revenues collected from polluters. There is also the moral/equity issue concerning the extent of the polluters' obligation to compensate for past emissions (i.e. a form of environmental debt). As mentioned earlier, weighting the benefits and costs of climate change impacts according to the income levels of those who are affected, has also been suggested as one way of redressing inequitable outcomes. Kverndokk (1995) argued that conventional justice principles would favour the equitable allocation of future GHG emission rights on the basis of population. Equal *per capita* GHG emission rights (i.e. equal access to the global atmosphere) is consistent also with the UN human rights declaration underlining the equality of all human beings.

Traditionally, economic analysis has addressed efficiency and distributional issues separately – i.e. the maximization of net benefits is distinct from who might receive such gains. Recent work has sought to interlink efficiency and equity more naturally. For example, environmental services could be considered public goods, and incorporated into appropriate markets as privately produced public goods (Chichilnisky and Heal, 2000). Some social equity and economic efficiency interactions are discussed in Box 2.

Several concepts from contemporary environmental and social analysis are relevant for developing climate change response options, including the concepts of durability, optimality, safe limits, carrying capacity, irreversibility, non-linear responses, and the precautionary principle. Broadly speaking, durability and optimality are complementary and potentially convergent approaches (see earlier discussion). Under the durability criterion, an important goal would be to determine the safe limits for climate change within which the resilience of global ecological and social systems would not be seriously threatened. In turn, the accumulations of GHGs in the atmosphere would have to be constrained to a point that prevented climate change from exceeding these safe margins. It is considered important to avoid irreversible damage to bio-geophysical systems and prevent major disruption of socioeconomic systems. Some systems may respond to climate change in a non-linear fashion, with the potential for catastrophic collapse. Thus, the precautionary principle argues that lack of scientific certainty about climate change effects should not become a basis for inaction, especially where relatively low cost steps to mitigate climate change could be undertaken as a form of insurance (UNFCCC, 1993).

3.1.3 Case Study 1: The interplay of optimality and durability in determining appropriate global GHG emission target levels.

Optimization and durability based approaches can facilitate the determination of target GHG emission levels (Munasinghe, 1998a). Under an economic optimizing framework, the ideal solution would be first to estimate the long-run marginal abatement costs (MAC) and the marginal avoided damages (MAD) associated with different GHG emission profiles – see Figure 5c, where the error bars on the curves indicate measurement uncertainties (IPCC, 1996a). The optimal emission levels would be determined at the point where future benefits (in terms of climate change damage avoided by reducing one unit of GHG emissions) are just equal to the corresponding costs (of mitigation measures required to reduce that unit of GHG emissions), i.e. MAC = MAD at point R_{OP}.

Durable strategies become more relevant when we recognize that MAC and/or MAD might be poorly quantified and uncertain. Figure 5b assumes that MAC is better defined than MAD. First, MAC is determined using techno-economic least-cost analysis – an optimizing approach. Next, the target emissions are set on the basis of the affordable safe minimum standard (at R_{AM}), which is the upper limit on costs that will still avoid unacceptable socioeconomic disruption – this is closer to the durability approach.

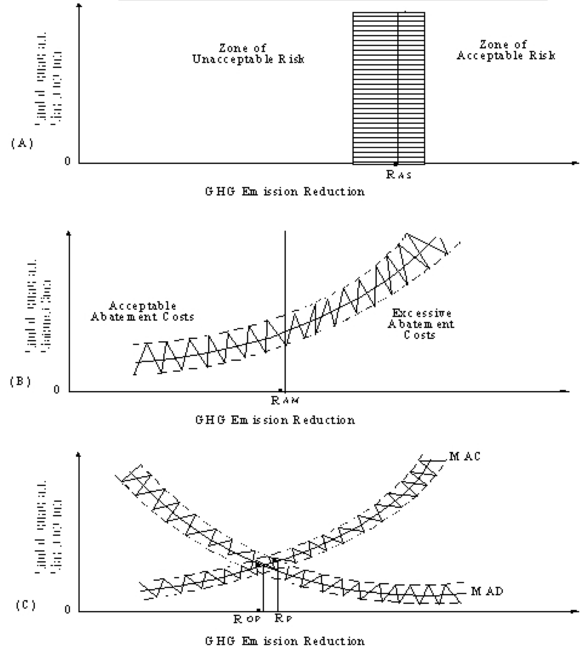
Finally, Figure 5a indicates an even more uncertain world, where neither MAC nor MAD is defined. Here, the emission target is established on the basis of an absolute standard (R_{AS}) or safe limit, which would avoid an unacceptably high risk of damage to ecological (and/or social) systems. This last approach would be more in line with the durability concept.

3.1.4 Case Study 2: Combining efficiency and equity to facilitate South-North cooperation for climate change mitigation

GHG mitigation efforts will require worldwide cooperation. Figure 6 clarifies the basic rationale for greater North to South resource transfers and technical cooperation, and also highlights how the sustainomics approach elucidates the complex interaction of economic efficiency, social equity and global environmental considerations in addressing the climate change problem. The curve ABCDE indicates the combined marginal abatement costs (MAC) for a pair of countries (one developing or southern and the other industrialized or northern). In other words, the graph shows the additional costs of adopting various GHG-reducing schemes (over and above the costs of conventional technologies), plotted against the amount of avoided emissions. The portion AB indicates negative costs, to represent so-called ‘win-win’ or ‘no regrets’ options – like energy efficiency schemes for which cost-benefit analysis will show a net economic gain even before GHG abatement benefits have been considered (i.e. where the value of conventional energy savings exceed project costs).

Figure 5.

Figure 5. Determining abatement targets: (a) absolute standard; (b) affordable safe minimum standard; (c) cost-benefit optimum



Source: **Adapted from IPCC 1996c, Figure 5.10**

Other measures like fuel switching, new and renewable technologies, carbon sinks, and advanced energy technologies are likely to appear on the rising part (BCDE) of the curve. Many lower cost options for GHG emissions reduction (such as CF), would be in the developing country, whereas more costly alternatives would lie in the industrialized nation.

On its own, a typical developing country would be willing to pursue abatement measures only up to the point K – where MAC is equal to the benefit of avoided climate change costs or MAD(DC) accruing purely to that country. Ideally, all options should be pursued in both countries, up to the point E, where the additional costs (MAC combined) of the marginal unit of emissions curtailed are equal to the corresponding benefits (MAD global) of avoided global warming impacts. Although the benefits curves will not be known with precision, the precautionary principle and the high risk involved would suggest that the point E would be far to the right of K.

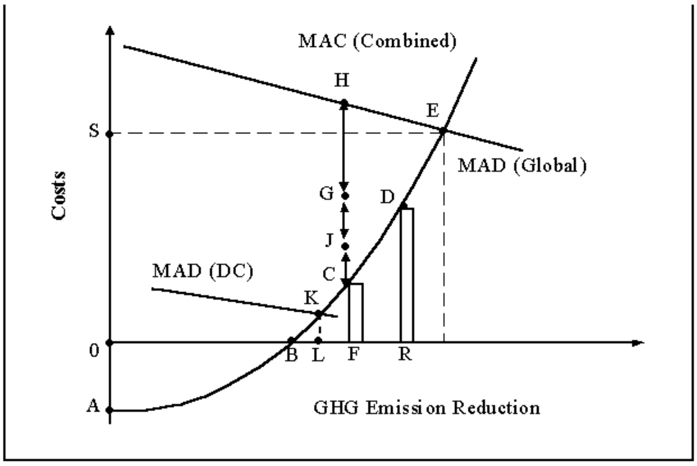


Figure 6 Rationale for south-north cooperation and interplay of efficiency and equity

Source: Munasinghe and Munasinghe [1993]

First, we explore the implications of this broad environmental rationale for resource transfers from the North to the South. In this context, consider a representative GHG mitigation project (e.g. re-afforestation) in the developing country, where the additional costs of GHG emissions reduction is CF. It would be *economically efficient* for the global community to finance these costs (on a grant basis) in the developing country, because they will thereby realize the global net benefits HC (i.e. HC = HF − CF). This would effectively internalize the global environmental externality.

Second, we make the case for a bilateral transfer of resources from an industrialized to a developing country. Consider the cost of a project DR (e.g. conversion of coal plants), which seeks to reduce GHG emissions in the industrialized country. This country could realize a cost saving GC by transferring an amount CF to the developing country, while still achieving the same global emissions reduction. The foregoing could be the basis for bilateral cooperative schemes such as joint implementation (JI) and/or the clean development mechanism (CDM), under the Kyoto Protocol. To the extent that net benefits HC, and cost savings GC are significant, it would be both *equitable* and *efficient* for the industrial nation to give the poorer developing country more resources than the (minimum) breakeven reimbursement CF. In other words, the equity principle of sustainomics would favour the sharing of cost savings GC between the two cooperating nations. The underlying ethical argument would be based on the facts that:

- both the historical and current levels of *per capita* GHG emissions from the industrial country are likely to be many times the corresponding contribution from the developing nation;

- the *per capita* income and ability to pay of the industrial country would be many times greater than those of the developing country.

This would also provide a greater incentive for the developing country to participate in such a scheme. The same argument has been made in the case of South-North cooperation to reduce ozone-depleting substances under the Montreal Protocol (Munasinghe and King, 1992).

3.2 National-economy scale: macroeconomic management

Conventional economic valuation of environmental impacts is a key step in incorporating the results of project level environmental assessment into economic decision-making – e.g. cost-benefit analysis (see also Figure 4 and associated discussion). At the macroeconomic level, recent work has focused on incorporating environmental considerations such as depletion of natural resources and pollution damage into the system of national accounts (UN Statistical Office, 1993; Atkinson *et al.*, 1997). These efforts have yielded useful new indicators and measures such as the system of environmentally adjusted environmental accounts (SEEA), green gross national product, and genuine savings, which adjust conventional macroeconomic measures to allow for environmental effects.

Meanwhile, national policy-makers routinely make many key macro-level decisions that could have (often inadvertent) environmental and social impacts, which are far more significant than the effects of local economic activities. These pervasive and powerful measures are aimed at achieving economic development goals like accelerated growth – which invariably have a high priority in national agendas. Typically, many macroeconomic policies seek to induce rapid growth, which in turn could potentially result in greater environmental harm or impoverishment of already disadvantaged groups. More attention needs to be paid to such economy policies, whose environmental and social linkages have not been adequately explored in the past (Munasinghe and Cruz, 1994).

Clearly, sustainable development strategies that are consistent with other national development policies are more likely to be effective than isolated technological or policy options. In particular, the highest priority needs to be given to finding ‘win-win policies’, which not only achieve conventional macroeconomic objectives, but also make local and national development efforts more sustainable. Such policies could help to build support for sustainable development strategies among the traditional decision-making community, and conversely make sustainable development specialists more sensitive to shorter term macroeconomic needs. They would reduce the potential for conflict between two powerful current trends – the growth oriented, market based economic reform process, and protection of the environment.

3.2.1 Scope of policies and range of impacts

The most powerful economic management tools currently in common use are economy reforms, which include structural adjustment packages. Economy (or countrywide) policies consist of both sectoral and macroeconomic policies which have widespread effects throughout the economy. Sectoral measures mainly involve a variety of economic instruments, including pricing in key sectors (for example, energy or agriculture) and broad sectorwide taxation or subsidy programmes (for example, agricultural production subsidies, and industrial investment incentives). Macroeconomic measures are even more sweeping, ranging from exchange rate, interest rate, and wage policies, to trade liberalization, privatization, and similar programs. Since space limitations preclude a comprehensive review of interactions between economy policies and sustainable development, we briefly examine several examples that provide a flavour of the possibilities involved (for details, see Munasinghe, 1997; Jepma and Munasinghe, 1998).

On the positive side, liberalizing policies such as the removal of price distortions and promotion of market incentives have the potential to improve economic growth rates, while increasing the value of output per unit of pollution emitted (i.e. so called 'win-win' outcomes). For example, reforms that improve the efficiency of energy use could reduce economic waste and lower the severity of air pollution. Similarly, improving property rights and strengthening incentives for better land management not only yield economic gains but also reduce deforestation of open access lands (e.g. due to slash and burn agriculture).

At the same time, growth-inducing economy policies could lead to increased environmental and social damage, unless the macro-reforms are complemented by additional environmental and social measures. Such negative impacts are invariably unintended and occur when some broad policy changes are undertaken while other hidden or neglected economic and institutional imperfections persist (Munasinghe and Cruz, 1994). In general, the remedy does not require reversal of the original reforms, but rather the implementation of additional complementary measures (both economic and non-economic) that mitigate climate change. For example, export promotion measures and currency devaluation might increase the profitability of timber exports (see the case study below). This in turn could further accelerate deforestation that was already under way due to low stumpage fees and open access to forest lands. Establishing property rights and increasing timber charges would reduce deforestation, without interrupting the macroeconomic benefits of trade liberalization.

Similarly, market-oriented liberalization could lead to economic expansion and the growth of wasteful energy-intensive activities in a country where subsidized energy prices persisted. Eliminating the energy price subsidies could help to reduce local air pollution and net GHG emissions while enhancing macroeconomic gains. Countrywide policies could also influence adaptation to climate change, negatively or positively. For example, national policies that encouraged population movement into low-lying coastal areas might increase their vulnerability to future impacts of sea-level rise. On the other hand, government actions to protect citizens from natural disasters – such as investing in safer physical infrastructure or strengthening the social resilience of poorer communities – could help to reduce vulnerability to extreme weather events associated with future climate change (Clarke and Munasinghe, 1995).

In this context, the sustainomics approach helps to identify and analyse economic-environmental-social interactions, and formulate effective sustainable development policies, by linking and articulating these activities explicitly. Implementation of such an approach would be facilitated by constructing a simple Action Impact Matrix or AIM, as described below in Case Study 3 (Munasinghe and Cruz, 1994).

3.2.2 Case Study 3: Action impact matrix (AIM) for policy analysis

The sustainomics approach seeks to identify and analyse economic-environmental-social interactions, and thereby formulate more sustainable development policies. One tool that would facilitate the implementation of such an approach is the Action Impact Matrix (AIM) – a simple example is shown in Table 1, although an actual AIM would be very much larger and more detailed (Munasinghe, 1993, 1998b). Such a matrix helps to promote an integrated view, meshing development decisions with priority economic, environmental and social impacts. The far left column of the table lists examples of the main development interventions (both policies and projects), while the top row indicates some typical sustainable development issues. Thus the elements or cells in the matrix help to:

- identify explicitly the key linkages;
- focus attention on methods of analysing the most important impacts;
- suggest action priorities and remedies.

At the same time, the organization of the overall matrix facilitates the tracing of impacts, as well as the coherent articulation of the links among a range of development actions - both policies and projects.

A stepwise procedure, starting with readily available data, has been used effectively to develop the AIM in several country studies (Munasinghe and Cruz, 1994). This process has helped to harmonize views among those involved (economists, ecologists, sociologists and others), thereby improving the prospects for successful implementation.

Screening and problem identification

One of the early objectives of the AIM-based process is to help in *screening and problem identification* – by preparing a preliminary matrix that identifies broad relationships, and provides a qualitative idea of the magnitudes of the impacts. Thus, the preliminary AIM would be used to prioritize the most important links between policies and their sustainability impacts. For example, in row 2 of Table 1, a currency devaluation aimed at improving the trade balance may make timber exports more profitable and lead to deforestation of open access forests. Column 3 indicates severe land degradation and biodiversity. Lower down in the same column, one appropriate remedy might involve complementary measures to strengthen property rights and restrict access to forest areas.

A second example shown in row 3 involves increasing energy prices closer to marginal costs – to improve energy efficiency, while decreasing air pollution and GHG emissions. A complementary measure indicated in column 4 consists of adding pollution taxes to marginal energy costs, which will further reduce air pollution and GHG emissions. Increasing public sector accountability will reinforce favourable responses to these price incentives, by reducing the ability of inefficient firms to pass on cost increases to consumers or to transfer their losses to the government. In the same vein, a major hydroelectric project is shown lower down in the Table as having two adverse impacts (inundation of forested areas and village dwellings), as well as one positive impact (the replacement of thermal power generation, thereby reducing air pollution and GHG emissions). A re-forestation project coupled with resettlement schemes may help address the negative impacts.

Table 1 A simplified preliminary Action Impact Matrix (AIM) (source: Munasinghe and Cruz, 1994).

		Impacts on key sustainable development issues			
Activity/policy[a]	Main objective	Land degradation, biodiversity loss	Air pollution GHG emissions	Resettlement and social effects	other
Macroeconomic and sectoral policies	Macroeconomic and sectoral improvements	Positive impacts due to removal of distortions Negative impacts mainly due to remaining constraints			
Exchange rate	Improve trade balance and economic growth	(−H) (deforest open-access areas)			
Energy pricing	Improve energy use economic and efficiency		(+M) (energy efficiency)		
Others					
Complementary measures and remedies[b]	Specific socioeconomic and environmental gains	Enhance positive impacts and mitigate negative impacts (above) of broader macroeconomic and sectoral policies			
Market based			(+M) (pollution tax)		
Non-market based		(+H) (property rights)	(+M) (public sector accountability)		
Investment Projects	Improve effectiveness of investments	Investment decisions made more consistent with broader policy and institutional framework			
Project 1 (*Hydro dam*)		(−H) (inundate forests)	(+M) (displace fossil fuel use)	(−M) (displace people)	
Project 2 *(Re-forest and relocate)*		(+H) (replant forests)		(+M) (relocate people)	
Project N					

[a] A few examples of typical policies and projects as well as key economic, environmental and social issues are shown. Some illustrative but qualitative impact assessments are also indicated: thus + and – signify beneficial and harmful impacts, while H and M indicate high and moderate intensity. The AIM process helps to focus on the highest priority socioeconomic and environmental issues.

[b] Commonly used market-based measures include effluent charges, tradable emission permits, emission taxes or subsidies, bubbles and offsets (emission banking), stumpage fees, royalties, user fees, deposit-refund schemes, performance bonds, and taxes on products (such as fuel taxes). Non-market based measures comprise regulations and laws specifying environmental standard (such as ambient standards, emission standards, and technology standards) which permit or limit certain actions ('dos' and 'don'ts').

This matrix-based approach therefore encourages the systematic articulation and coordination of policies and projects to make development more sustainable. Based on readily available data, it would be possible to develop such an initial matrix for many countries.

Analysis and remediation

This process may be developed further to assist in *analysis* and *remediation*. For example, more detailed analyses and modelling may be carried out for those matrix elements in the preliminary AIM that had been already identified as representing high priority linkages between economywide policies and economic, environmental and social impacts. This, in turn, would lead to a more refined and updated AIM, which would help to quantify impacts and formulate additional policy measures to enhance positive linkages and mitigate negative ones.

The types of more detailed analysis that could help to determine the final matrix would depend on planning goals and available data and resources. They may range from fairly simple methods to rather sophisticated economic, ecological and social models, in the sustainomics toolkit.

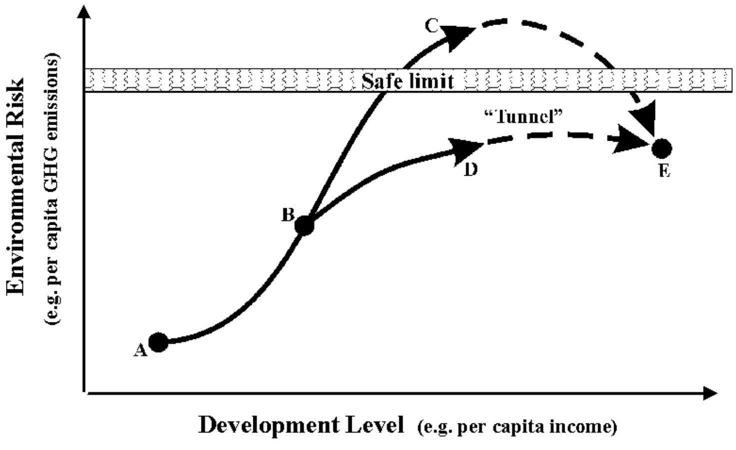
3.2.3 Case Study 4: Restructuring growth to address climate change issues

Economic growth continues to be a widely pursued objective of most governments, and therefore, the sustainability of long term growth is a key issue (Munasinghe *et al.*, 2001) – in particular, reducing the intensity of GHG emissions of human activities is an important step in mitigating climate change (Munasinghe, 2000). Given that the majority of the world population lives under conditions of absolute poverty, a climate change strategy that unduly constrained growth prospects in those areas would be more unattractive. A sustainomics based approach would seek to identify measures that modify the structure of development and growth rather than restricting it (see Figure 4), so that GHG emissions are mitigated and adaptation options enhanced.

The above approach is illustrated in Figure 7, which shows how a country's GHG emissions might vary with its level of development. One would expect carbon emissions to rise more rapidly during the early stages of development (along AB), and begin to level off only when *per capita* incomes are higher (along BC). A typical developing country would be at a point such as B on the curve, and an industrialized nation might be at C. The key point is that if the developing countries were to follow the growth path of the industrialized world, then atmospheric concentrations of GHGs would soon rise to dangerous levels. The risk of exceeding the safe limit (shaded area) could be avoided by adopting sustainable development strategies that would permit developing countries to progress along a path such as BD (and eventually DE), while also reducing GHG emissions in industrialized countries along CE.

As outlined earlier, growth-inducing economywide policies could combine with imperfections in the economy to cause environmental harm. Rather than halting economic growth, complementary policies may be used to remove such imperfections and thereby protect the environment. It would be fruitful to encourage a more proactive approach whereby the developing countries could learn from the past experiences of the industrialized world – by adopting sustainable development strategies and climate change measures which would enable them to follow development paths such as BDE, as shown in Figure 7 (Munasinghe, 1998b). Thus, the emphasis is on identifying policies that will help delink carbon emissions and growth, with the curve in Figure 7 serving mainly as a useful metaphor or organizing framework for policy analysis.

Figure 7. Environmental Risk versus Development Level



Source: adapted from Munasinghe [1995].

This representation also illustrates the complementarity of the optimal and durable approaches discussed earlier. It has been shown that the higher path ABC in Figure 7 could be caused by economic imperfections which make private decisions deviate from socially optimal ones (Munasinghe, 1998c). Thus the adoption of corrective policies that reduce such divergences from optimality and thereby reduce GHG emissions per unit of output would facilitate movement along the lower path ABD. Concurrently, the durability viewpoint suggests that flattening the peak of environmental damage (at C) would be especially desirable to avoid exceeding the safe limit or threshold representing dangerous accumulations of GHGs (shaded area in Figure 7).

Several authors have econometrically estimated the relationship between GHG emissions and *per capita* income using cross-country data and found curves with varying shapes and turning points (Holtz-Eakin and Selden, 1995; Sengupta, 1996; Unruh and Moomaw, 1998; Cole *et al.*, 1997). One reported outcome is an inverted U-shape (called the environmental Kuznets curve or EKC) – like the curve ABCE in the Figure. In this case, the path BDE (both more socially optimal and durable) could be viewed as a sustainable development 'tunnel' through the EKC (Munasinghe, 1995, 1998c).

3.3 Sub-national scale: energy-sector planning and forest ecosystem management

At the sub-national scale, sustainable development issues arise in various forms. In this section, we apply the sustainomics approach to two case studies dealing with such issues: (1) in an important sector of the Sri Lankan economy concerned with energy; and (2) in a key ecological region involving a tropical rainforest in Madagascar.

3.3.1 Case Study 5: Improving energy-sector decision-making in Sri Lanka

Actions that affect an entire economic sector or region of a country have significant and pervasive environmental and social impacts. Thus typically, policies in a given sector like energy have widespread impacts on other sectors of the economy. This requires an integrated, multi-sectoral analytic framework (Munasinghe, 1990).

Sustainable energy development framework

A framework for sustainable energy decision-making is depicted in Figure 8. The middle column of the Figure shows the core of the framework comprising an integrated multilevel analysis that can accommodate issues ranging from the global scale down to the local or project level. At the top level, individual countries constitute elements of an international matrix. Economic and environmental conditions imposed at this global level constitute exogenous inputs or constraints on national level decision-makers.

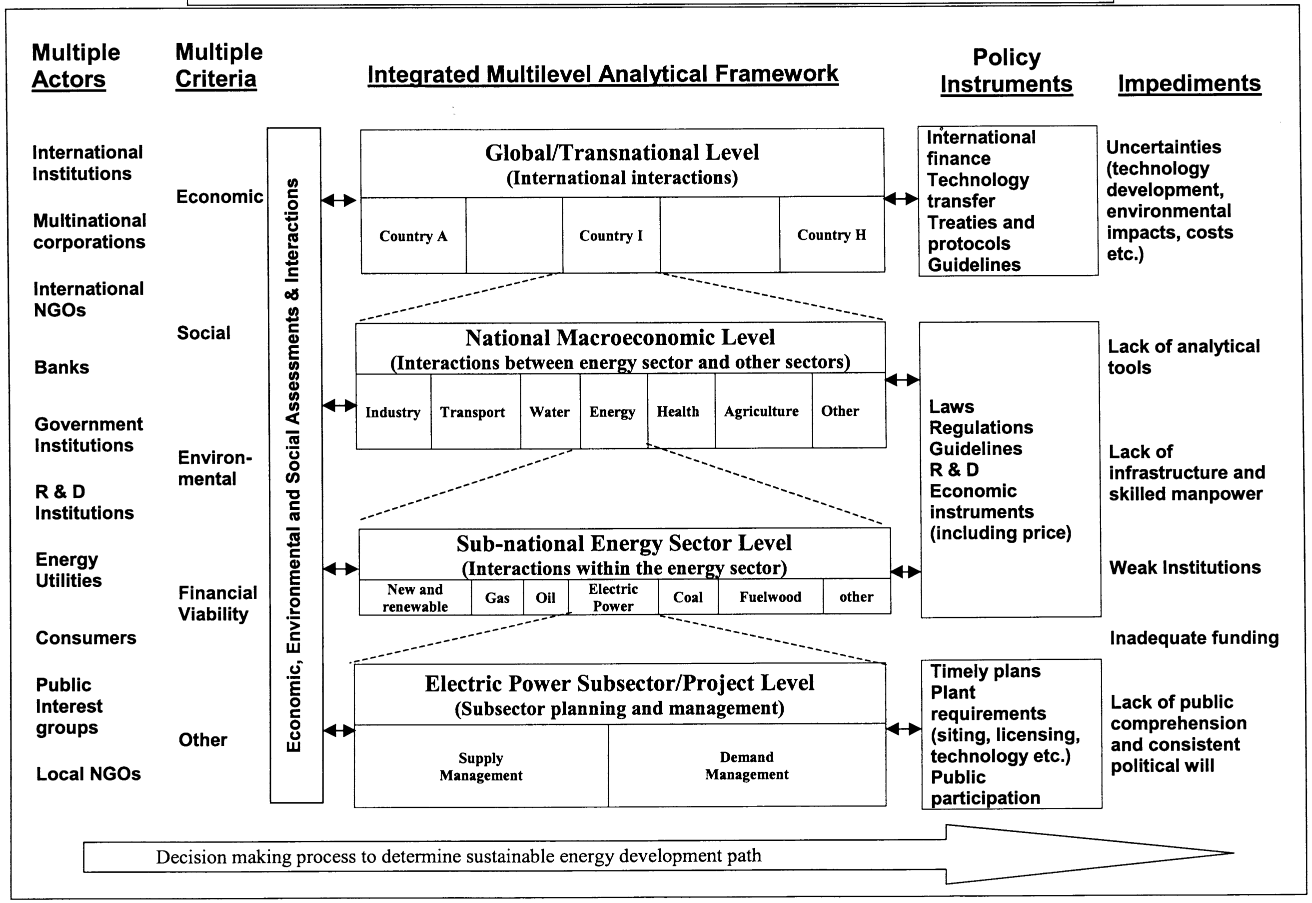
The next level focuses on the multi-sectoral national economy, of which the energy sector is one element. This level of the framework recognizes that planning within the energy sector requires analysis of the links between that sector and the rest of the economy. At the third or sub-national level, we focus on the energy sector as a separate entity composed of sub-sectors such as electricity, petroleum products and so on. This permits detailed analysis, with special emphasis on interactions among different energy sub-sectors. Finally, the most disaggregate and lowest hierarchical level pertains to energy analysis within each of the energy sub-sectors. At this level, most of the detailed energy planning and implementation of projects is carried out by line institutions (both public and private).

In practice, the various levels of analysis merge and overlap considerably, requiring that inter-sectoral linkages should be carefully examined. Energy-economic-environmental-social interactions (represented by the vertical bar) tend to cut across all levels and need to be incorporated into the analysis as far as possible. Such interactions also provide important paths for incorporating environmental and social considerations into sustainable energy development policies.

Methodology

The incorporation of environmental and social externalities into decision-making is particularly important in the electric power sector. It is also clear that in order for environmental and social concerns to play a real role in power sector decision-making, one must address these issues early – at the sectoral and regional planning stages, rather than later at the stage of environmental and social assessment of individual projects. Many of the valuation techniques discussed earlier are most appropriate at the micro-level, and may therefore be very difficult to apply in situations involving choices among a potentially large number of technology, site, and mitigation options. Therefore, multi-criteria analysis (MCA) may be applied, since it allows for the appraisal of options with different objectives and varied costs and benefits, which are often assessed in differing units of measurement.

Figure 8. Framework for sustainable energy development Source: adapted from Munasinghe [1990].



Such an approach was used by Meier and Munasinghe (1994) in a study of Sri Lanka, to demonstrate how externalities could be incorporated into power system planning in a systematic manner. Sri Lanka presently depends largely on hydro power for electricity generation, but over the next decade the main choices seem to be large coal- or oil-fired stations, or hydro plants whose economic returns and environmental impacts are increasingly unfavourable. In addition, there is a wide range of other options (such as wind power, increasing use of demand side management, and system efficiency improvements), that make decision-making quite difficult – even in the absence of unusual environmental concerns. The study is in its focus on system-wide planning issues, as opposed to the more usual policy of assessing environmental concerns only at the project level after the strategic sectoral development decisions have already been made.

The methodology involves the following steps: (a) definition of the generation options and their analysis using sophisticated least-cost system planning models; (b) selection and definition of the attributes, selected to reflect planning objectives; (c) explicit economic valuation of those impacts for which valuation techniques can be applied with confidence – the resultant values are then added to the system costs to define the overall attribute relating to economic cost; (d) quantification of those attributes for which explicit economic valuation is inappropriate, but for which suitable quantitative impact scales can be defined; (e) translation of attribute value levels into value functions (known as 'scaling'); (f) display of the trade-off space, to facilitate understanding of the trade-offs to be made in decision-making; and (g) definition of a candidate list of options for further study; this also involves the important step of eliminating inferior options from further consideration.

Main results

The main set of sectoral policy options examined included: (a) variations in the currently available mix of hydro, and thermal (coal and oil) plants; (b) demand-side management (using the illustrative example of compact fluorescent lighting); (c) renewable energy options (using the illustrative technology of wind generation); (d) improvements in system efficiency (using more ambitious targets for transmission and distribution losses than the base case assumption of 12% by 1997); (e) clean coal technology (using pressurized fluidized bed combustion (PFBC) in a combined cycle mode as the illustrative technology); and (f) pollution control technology options (illustrated by a variety of fuel switching and pollution control options such as using imported low sulfur oil for diesels, and fitting coal-burning power plants with flue gas desulfurization (FGD) systems).

Great care needs to be exercised in criteria or attribute selection – they should reflect issues of national as well as local project level significance, and ought to be limited in number. To capture the potential impact on global warming, CO_2 emissions were defined as the appropriate proxy. Health impacts were measured through population-weighted increments in both fine particulates and NO_x attributable to each source. To capture the potential biodiversity impacts, a probabilistic index was derived (see Box 4 for details). As an illustrative social impact, employment creation was used.

Figure 9a illustrates a typical trade-off curve for biodiversity (see also, the earlier discussion on MCA in the context of Figure 2). The 'best' solutions lie closest to the origin. The so-called trade-off curve is defined by the set of 'non-inferior' solutions, representing the set of options that are superior, regardless of the weights assigned to the different objectives. For example, on this curve, the option defined as ‘no hydro’ is better than the option ‘wind’, in terms of both economic cost and biodiversity loss.

Box 4 Developing a preliminary biodiversity index

In electric power plant evaluation, detailed site-specific information at potential sites is unlikely to be available at the long-range system planning stage. Thus, the only quantification of biodiversity impacts that appears possible at this level of aggregation is a probabilistic estimate that gives the decision-maker advance information about the likelihood that a more detailed environmental impact assessment will reveal adverse effects on an endemic species, significant impacts on ecosystems of high biological diversity, or degradation of a habitat already in a marginal condition. It should be noted that endemicity and biodiversity are not necessarily correlated, since an endemic species may be encountered in an area of low biodiversity, and areas of high biodiversity may contain no endemic species. However, endemic species in Sri Lanka are most likely to be encountered in areas of high biodiversity.

A biodiversity index must reflect several key characteristics. First is the nature of the impacted system itself. In Table B4, the main agro-ecological zones encountered in Sri Lanka are ranked and assigned a value (w_j) that captures the relative biodiversity value of different habitats. The scale is to be interpreted as a strict ratio scale (i.e. zero indicates zero amount of the characteristic involved, and a habitat value of 0.1 implies ten times the value of a habitat assigned the value of 0.01). The second element concerns the *relative* valuation, because the *value* of the area lost is a function of the proportion of the habitat that is lost. For example, the loss of the *last* hectare of an ecosystem would be unacceptable, and hence assigned a very large value (even if the habitat involved were of low biodiversity, such as a sand dune) whereas the loss of one hectare out of 10,000 ha would be much less valuable.

The total biodiversity index value associated with site i, is defined as:

$$E_i = \sum_j w_j A_{ij}$$

where A_{ij} is the ha of ecosystem of type *j* at site *i*, and w_j is relative biodiversity value of type *j* (as defined in Table B4).

Because E_i would tend to be correlated with reservoir size (i.e. land area inundated and energy-storage capacity), two further scaled indices may be defined as follows:

$$F_i = E_i / [\sum_j A_{ij}] = E_i / [\text{total land area affected at site } i]$$

$$G_i = E_i / [\text{hydroelectric energy generated per year at site } i$$

Thus, F_i is the average biodiversity index value per hectare of affected land, and G_i is the average biodiversity index value per unit of energy produced per year.

Figure 9a illustrates a typical trade-off curve for biodiversity (see also, the earlier discussion on MCA in the context of Figure 2). The ‘best’ solutions lie closest to the origin. The so-called trade-off curve is defined by the set of ‘non-inferior’ solutions, representing the set of options that are superior, regardless of the weights assigned to the different objectives. For example, on this curve, the option defined as ‘no hydro’ is better than the option ‘wind’, in terms of both economic cost and biodiversity loss.

Table B4 Relative biodiversity values of agro-ecological zones in Sri Lanka (adapted from Meier and Munasinghe, 1994).

Rank	Ecosystem	Relative biodiversity value
1	Lowland wet evergreen forest	0.98
2	Lowland moist evergreen forest	0.98
3	Lower montane forest	0.90
4	Upper montane forest	0.90
5	Riverline forest	0.75
6	Dry mixed evergreen forest	0.5
7	Villus	0.4
8	Mangroves	0.4
9	Thorn forest	0.3
10	Grasslands	0.3
11	Rubber lands	0.2
12	Home gardens	0.2
13	Salt marshes	0.1
14	Sand dunes	0.1
15	Coconut lands	0.01

While most of the options have an index value that falls in the range of 50–100, the no-hydro option has an essentially zero value, because the thermal projects that replace hydro plants in this option tend to lie at sites of poor biodiversity value (either close to load centres or on the coast). Meanwhile, wind plants would require rather large land area, and their biodiversity index is higher. However, the vegetation in the area on the south coast (where the wind power plants would be located) has relatively low biodiversity value, and therefore the overall biodiversity impact of this option is small. In summary, the best options (on the trade-off curve) include the no-hydro, and run-of-river hydro options that require essentially zero inundation. Note the extreme outlier at the top right hand corner, which is the Kukule hydro dam – it has a biodiversity loss index (B = 530) that is an order of magnitude larger than for other options (B = 50 to 70).

A quite different trade-off curve was derived between health impacts and average incremental cost, as illustrated in Figure 9b. Note that the point ‘iresid’ on the trade-off curve (which calls for the use of low sulfur imported fuel oil at diesel plants), is better than the use of flue gas desulfurization systems (point ‘FGD’) – in terms of both economic cost and environment.

Conclusions

The case study draws several useful conclusions.

First, the results indicate that those impacts for which valuation techniques are relatively straightforward and well-established – such as valuing the opportunity costs of lost production from inundated land, or estimating the benefits of establishing fisheries in a reservoir – tend to be quite small in comparison with overall system costs, and their inclusion into the benefit-cost analysis does not materially change results.

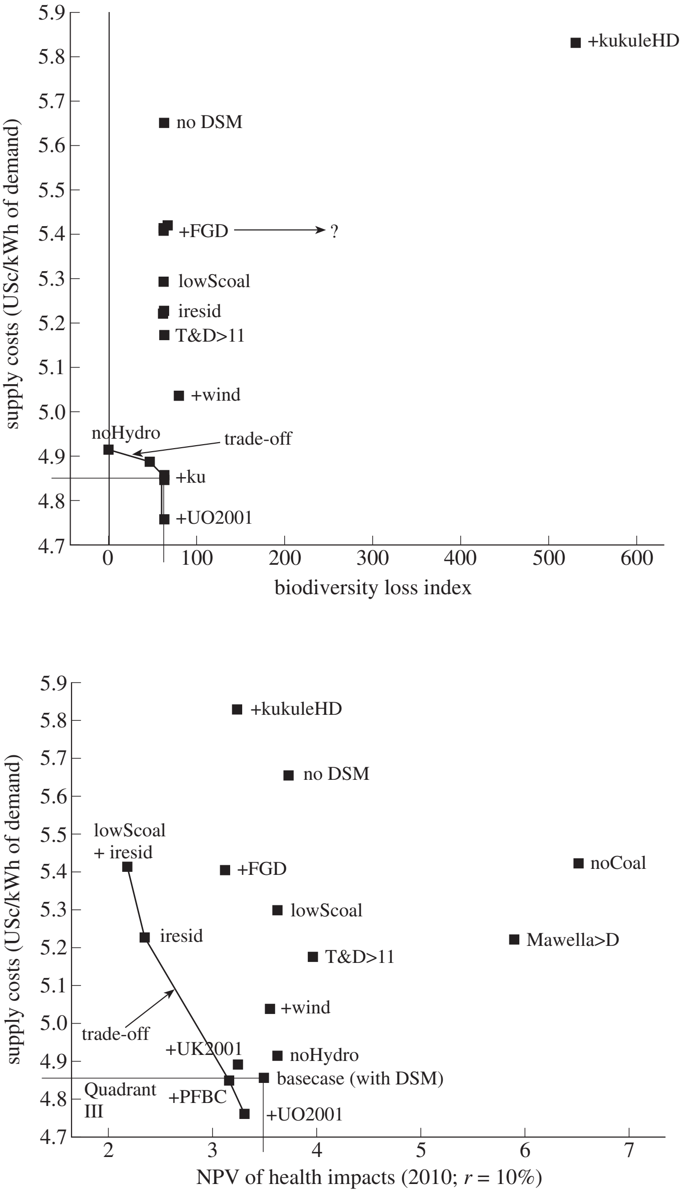


Figure 9 Trade-off curves between economic costs and (a) health impacts; and (b) biodiversity impacts (Meier and Munasinghe, 1994).

Second, even in cases where explicit valuation may be difficult, such as in the case of mortality and morbidity effects of air pollution, implicit valuation based on analysis of the trade-off curve can provide important guidance to decision-makers.

Third, the case study indicated that certain options were in fact clearly inferior, or clearly superior, to all other options when one examines all impacts simultaneously. For example, the high dam version of the Kukule hydro project can be safely excluded from all further consideration here, as a result of poor performance on all attribute scales (including the economic one). Fourth, the results indicate that it is possible to derive attribute scales that can be useful proxies for impacts that may be difficult to value. For example, use of the population-weighted incremental ambient air pollution scale as a proxy for health impacts permitted a number of important conclusions that are independent of the specific economic value assigned to health effects.

Finally, with respect to the practical implications for planning, the study identified several specific recommendations on priority options, including (i) the need to systematically examine demand side management options, especially fluorescent lighting; (ii) the need to examine whether the present transmission and distribution loss reduction target of 12% ought to be further reduced; (iii) the need to examine the possibilities of pressurized fluidized bed combustion technology for coal power; (iv) replacement of some coal-fired power plants (on the South coast) by diesel units; and (v) the need to re-examine cooling system options for coal plants.

3.3.2 Case Study 6: Rainforest management in Madagascar

Madagascar is one of the economically poorest and ecologically richest countries in the world, and it has been designated by the international community as a prime area for biodiversity whose ecosystems are also at great risk. The government of Madagascar is also taking steps to control forest degradation and to protect biodiversity. The results summarized below are from the first stage in the analysis to arrive at a rational decision concerning the proposed creation of the Mantadia National Park in Madagascar (Kramer *et al.*, 1995).

The establishment of a national park generates many indirect and direct costs and benefits. Costs arise from land acquisition (if the land had been previously privately owned), the hiring of park personnel, and the development of roads, visitors' facilities, and other infrastructure. Another important set of costs that are often ignored are the opportunity costs associated with the foregone uses of park land. Benefits include both use values and non-use values. Tourism can generate considerable revenues for the country from both entrance fees and travel expenditures. National parks also generate a number of non-use benefits, among which existence value and option value are important. Other benefits may include reduced deforestation, watershed protection and climate regulation.

This study measured some of the more important and difficult to measure economic impacts (including the impact of the park on local villagers and the benefits of the new park to foreign tourists), using the techniques summarized earlier in Box 3. Local people use the park area for rice cultivation and for gathering forest products. The creation of the park results in an opportunity cost in terms of lost production as presented in Table 2 – based on detailed surveys of 351 households in 17 villages with a 7.5 km radius of the proposed park. The foregone benefit net of inputs used is $91 per household per year. A comprehensive contingent valuation survey of the same villages, indicated that the willingness to pay (WTP) for access denied to the park area amounted to $108 per household per year.

A novel international travel cost (or recreation demand) model was used to determine the value of the proposed park to international tourists. The average tourist earned about $60 000 per year, had 15 years of education, and spent about $2900 per trip. Two empirical models – random utility (RU) and typical trip (TT) – were used to measure value, yielding estimates of $24 and $45 per trip. A separate contingent value survey of eco-tourists yielded a mean willingness-to-pay of $65 per trip.

Table 2 Value of agricultural and forestry activities (source: Kramer *et al.*, 1995).

Activity	Number of observations	Total annual value for all villages (US$)	Annual mean value per household (US$)
Rice	351	44 928	128
Fuelwood	316	13 289	38
Crayfish	19	220	12
Crab	110	402	3.7
Tenreck	21	125	6
Frog	11	71	6.5

Conclusions

All these results, and the total present value of benefits from these alternative uses of the rainforest (by local villagers or tourists) are summarized in Table 3. Several tentative conclusions can be drawn from the results of this study. Non-market valuation techniques can provide useful information for economic evaluation of national parks. A major strength of this study is the opportunity to compare valuation techniques. For the village component, the estimated benefits from park use based on two entirely different methods, opportunity cost analysis and contingent valuation method, were remarkably similar ($91 and $108 per household per year). The estimates of tourist benefits based on the travel cost method and contingent valuation method were somewhat more disparate ($24 to $65 per trip) but it is noteworthy that the benefit estimates are of the same order of magnitude. We note that the higher contingent valuation estimate may reflect some non-use values, while the recreation demand method is mainly for use value only.

This type of analysis would have implications for policy, investment decisions, resource mobilization, and project design and management. It can help governments to decide how to (a) allocate scarce capital resources among competing land-use activities; (b) choose and implement investments for natural resource conservation and development; (c) determine pricing, land use, and incentive policies; (d) determine compensation for local villagers for foregone access to forest areas designated as national parks; and (e) value the park as a global environmental asset to foreigners (thus attracting external assistance for conservation programmes at the local level).

At the same time, the findings indicate future issues. Reliance on WTP is fundamental to the economic approach, but tends to overemphasize the importance of value ascribed to richer foreign visitors. Assuming mutually exclusive alternative uses of the park, the costs (represented by the foregone benefits of villagers) are significantly less than potential benefits to tourists. If conflicting claims to park access were to be determined purely on this basis, residents (especially, the poor local villagers) are more likely to be excluded. Therefore, the socio-cultural concepts of sustainable development (especially intra-generational equity and distributional concerns) would need to be invoked to protect the basic rights of local residents – for example, in the form of a 'safe minimum' degree of access to park facilities, irrespective of WTP-based benefits that are dependent on income levels.

Table 3 Summary of economic analysis of Mantadia National Park.

Estimates of Welfare Losses to Local Villagers from Establishment of Park		
Method used	Annual mean value per household	Total present value[a]
Opportunity cost	US$91	US$673 078
Contingent valuation	108	566 070
Estimates of Welfare Gains to Foreign Tourists from Establishment of Park		
Method used	Annual mean value per trip	Total present value[a]
Recreation Demand 1 (RU)	US$24	US$936 000
Recreation Demand 2 (TT)	45	1 750 000
Contingent Valuation	65	2 530 000

[a] Discount rate = 10%.

3.4 Local-project scale: Fuelwood stoves and hydroelectric power

The procedures for conventional environmental and social assessment at the project/local level (which are now well accepted world wide), may be readily adapted to assess the environmental and social effects of micro-level activities (World Bank, 1998) – see also Figure 4. The OECD (1994) has pioneered the 'Pressure-State-Response' framework to trace socioeconomic-environment linkages. This P-S-R approach begins with the pressure (e.g. population growth), then seeks to determine the state of the environment (e.g. ambient pollutant concentration), and ends by identifying the policy response (e.g. pollution taxes). Specific methods for economic valuation of environmental and social impacts were described earlier in Box 3. The practical application of such techniques at the local level were illustrated in the previous case study. When valuation is not feasible for certain impacts, MCA may be used.

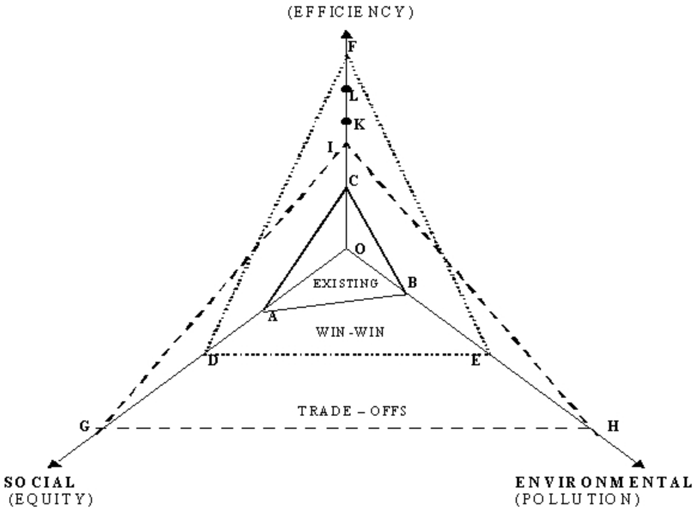
3.4.1 Case Study 7: Multicriteria analysis of a fuelwood stove project

Figure 10 illustrates how an MCA-based analysis at the project level could provide balanced treatment of economic, social and environmental considerations. The stylized project evaluation involves the case of an improved fuelwood burning stove.

As discussed earlier, MCA offers policy-makers an alternative when progress toward multiple objectives cannot be measured in terms of a single criterion (e.g. monetary values). Take the case of an efficient fuelwood stove – an end-use option for sustainable energy development. While the economic value of such a cookstove is measurable, its contribution to social and environmental goals is not easily valued in economic terms. As shown in Figure 10, outward movements along the axes trace improvements in three indicators: economic efficiency (net monetary benefits), social equity (improved health of poor energy users), and environmental pollution (reduced deforestation and GHG emissions).

We may assess the policy options as follows. First, triangle ABC represents the existing method of burning fuelwood (typically placing the cooking pot on three bricks). In this case, the indicators of economic efficiency, social equity, and overall environmental impact are all bad, because the stove uses fuelwood inefficiently, increases smoke inhalation (especially by women and children in poor households), and worsens GHG emissions and pressure on forest resources. Next, triangle DEF indicates a ‘win-win’ future option based on an improved fuelwood stove, in which all three indices improve. The economic gains would include monetary savings from reduced fuelwood use and increased productivity from reductions in acute respiratory infections, lung disease and cancer caused by pollutants in biomass smoke. Social gains would accrue from the fact that the rural poor benefit the most from this innovation – for example, due to the lighter health and labour burden on women and children, and the reduced time spent on collecting fuelwood, thereby increasing time spent on other productive activities. The environment benefits occur because more efficient use of fuelwood will reduce both deforestation and greenhouse emissions resulting from inefficient combustion.

Figure 10 Analysing the sustainability of an improved fuelwood stove using multicriteria analysis
Source: adapted from Munasinghe [1993]



After realizing such ‘win-win’ gains, other available options would require trade-offs. In triangle GIH, further environmental and social gains are attainable only at the expense of sharply increasing costs. For example, shifting from fuelwood to liquid petroleum gas (LPG) or kerosene as a fuel may increase economic costs, while yielding further environmental and social benefits. A policy-maker may not wish to make a further shift from DEF to GIH without knowing the relative weights that society places on the three indices – in sharp contrast to the move from ABC to DEF, which is unambiguously desirable. Such social preferences are often difficult to determine explicitly, but it is possible to narrow the options. Suppose a small economic cost, FL, yields the full social gain DG, while a large economic cost, LI, is required to realize the environmental benefit EH. Here, the social gain may better justify the economic sacrifice. Further, suppose that budgetary constraints limit costs to less than FK (where FL < FK < LI). Then, sufficient funds exist only to pay for the social benefits, and the environmental improvements will have to be delayed.

3.4.2 Case Study 8: Comparison of hydroelectric power projects

In this case study, MCA is used to compare hydroelectric power schemes (for details, see Morimoto and Munasinghe, 2000). The three main sustainable development issues that are considered comprise the economic costs of power generation, ecological costs of biodiversity loss, and social costs of resettlement.

The principal objective is to generate additional kilowatt-hours (kWh) of electricity to meet the growing demand for power in Sri Lanka. As explained earlier in the section on cost-benefit analysis (CBA), we assume that the benefits from each additional kWh are the same. Therefore, the analysis seeks to minimize the economic, social and environmental costs of generating one unit of electricity from different hydropower sites. Following the MCA approach, environmental and social impacts are measured in different (non-monetary) units, instead of attempting to economically value and incorporate them within the single-valued CBA framework.

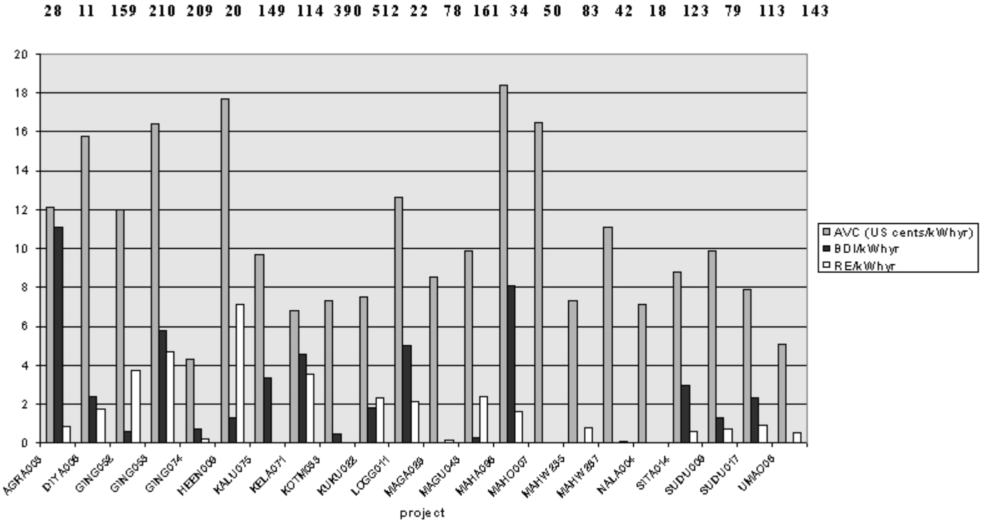
Environmental, social and economic indicators

Sri Lanka has many varieties of fauna and flora, many of which are endemic or endangered. Often large hydro projects destroy wildlife at the dam sites and the downstream areas. Hence, biodiversity loss was used as the main ecological objective. The biodiversity index described in Box 4 was estimated for each hydroelectric site.

Although dam sites are usually in less densely populated rural areas, resettlement is still a serious problem in most cases. In general, people are relocated from the wet to the dry zone where soils are less rich, and therefore the same level of agricultural productivity cannot be maintained. In the wet zone, multiple crops including paddy, tobacco, coconuts, mangos, onions, and chilies can be grown. However, these crops cannot be cultivated as successfully in the dry zone, due to limited access to water and poor soil quality. Living standards often become worse and several problems (like malnutrition) could occur. Moreover, other social issues such as erosion of community cohesion and psychological distress due to change in the living environment, might arise. Hence, minimising the number of people resettled due to dam construction is one important social objective..

The project costs are available for each site, from which the critical economic indicator – average cost per kWh per year – may be estimated (for details, see Ceylon Electricity Board (CEB), 1987, 1988, 1989). The annual energy generation potential at the various sites ranges from about 11 to 210 KWh (see Figure 11). All three variables, the biodiversity index, number of people resettled, and generation costs, are weighted by the inverse of the amount of electrical energy generated. This scaling removes the influence of project size and makes them more comparable.

Figure 11. Average generation costs (AVC), biodiversity index (BDI), and number of resettled people (RE) by hydroelectric project. All indices are per kWh per year. Numbers of people resettled and the biodiversity index are scaled for convenience (by the multipliers 10^{-5} and 10^{-9} respectively). The values at the top of the graph indicate the annual energy generation in gigawatt hours (GWh).



Source: CEB (1987); CEB (1988); Meier and Munasinghe (1994)

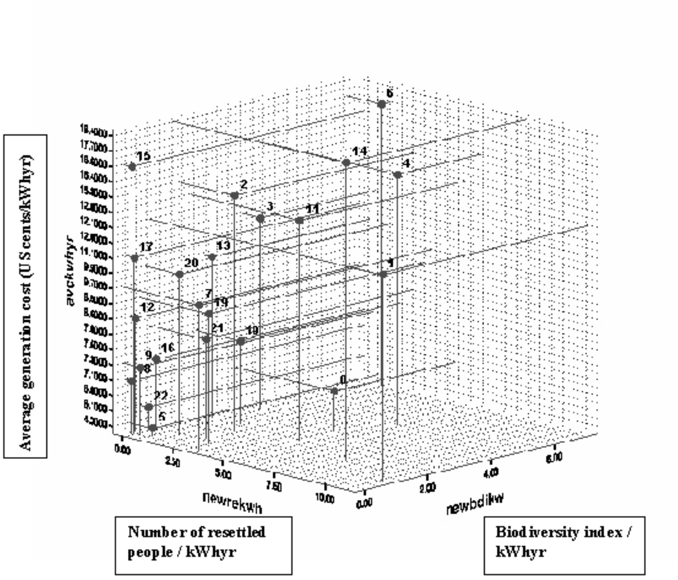
Some basic results

A simple statistical analysis shows that, pairwise, there is little correlation between the quantity of electricity generated, average generation cost, number of people resettled, and biodiversity index.

From Figure 11, it is clear that on a per kWh per year basis, the project named AGRA003 has the highest biodiversity index, HEEN009 has the highest number of resettled people, and MAHA096 has the highest average generation cost. Some important comparisons may be made. For example, KALU075 is a relatively large project where the costs are low, whereas MAHA096 is a smaller scheme with much higher costs with respect to all three indices. Another simple observation is that a project like KELA071 fully dominates GING053, since the former is superior in terms of all three indicators. Similar pairwise comparisons between other projects may be needed.

A three-dimensional analysis of sustainable development indicators for these hydropower sites is provided in Figure 12, where the axes represent economic, ecological, and social objectives, respectively. The distance from the origin to each coordinate point can be seen, and the closer to the origin, the better is the project in terms of achieving these three objectives. This type of analysis gives policy-makers some idea about which project is more favourable from a sustainable energy development perspective. Suppose we arbitrarily give all the three objectives an equal weight. Then, each project may be ranked according to its absolute distance from the origin. For example, rank 1 is given to the one closest to the origin, rank 2 is to the the second closest and so on, as shown in Figure 12. On this ad-hoc overall basis, from a sustainable energy development perspective, the most favourable project is GING074 (rank 1), whereas the least favourable one is MAHA096 (rank 22).

Figure 12. Three dimensional MCA of sustainable development indicators for various hydropower options.
Source: Morimoto, Munasinghe and Meier [2000]



Conclusions

The strength of this type of analysis is in helping policy-makers to compare project alternatives more easily and effectively. The simple graphical presentations are more readily comprehensible, and identify the sustainable development characteristics of each scheme quite clearly. The multi-dimensional analysis supplements the more conventional CBA, based on economic analysis alone. Since each project has different features, assessing them by looking at only one aspect (e.g. generation costs, effects on biodiversity, or impacts on resettlement) could be misleading.

There are some weaknesses in the MCA approach used here. First, for simplicity each major objective is represented by only one variable, assuming that all the other impacts are minor. In reality, there may be more than one variable that can describe the economic, social and environmental aspects of sustainable development. Further analysis that includes other variables may provide new insights. A second extension of this study is to include other renewable sources of energy in the analysis. Finally, a more sophisticated 3D graphic techniques may yield a better and clearer representation (Tufte, 1992).

4 Summary and concluding remarks

Sustainable development is one of the most important challenges facing humankind in the 21st century. While no universally acceptable practical definition exists as yet, the concept has evolved to encompass three major points of view: economic, social and environmental. Each viewpoint corresponds to a domain or system, which has its own distinct driving forces and objectives. The economic system is geared mainly towards improving human welfare (primarily through increases in the consumption of goods and services). The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social system seeks to enrich human relationships and achieve individual and group aspirations.

There is no single overarching framework for sustainable development, but sustainomics attempts to describe 'a trans-disciplinary, integrative, balanced, heuristic and practical meta-framework for making development more sustainable'. It seeks to synthesize key elements from core disciplines like ecology, economics, and sociology, as well as others such as anthropology, biotechnology, botany, chemistry, demography, engineering, ethics, geology, information technology, philosophy, physics, psychology, and zoology. Methods that cross the economy-society-environment interfaces are also important, including environmental and resource economics, ecological economics, conservation ecology, social capital and inclusion, energetics and energy economics, sociological economics, environmental sociology, cultural economics, economics of sociology, and sociology of the environment. While building on earlier work, sustainomics constitutes a more neutral expression which focuses attention explicitly on sustainable development, and especially issues of concern to the developing world.

Comprehensiveness is an important requirement because sustainable development involves every aspect of human activity and involves complex interactions among socioeconomic, ecological and physical systems. The scope of analysis needs to extend from the global to the local scale, cover time spans extending to centuries (for example, in the case of climate change), and deal with problems of uncertainty, irreversibility, and non-linearity. The approach must not only integrate the economic, social and environmental dimensions of sustainable development, as well as related methodologies and paradigms in a consistent manner, but also provide balanced treatment of all these elements. Balance is also needed in the relative emphasis placed on traditional development *versus* sustainability. No single discipline could cope with the multiplicity of issues involved, and therefore a trans-disciplinary framework is required which would address the many facets, from concept to actual practice. Furthermore, the precise definition of sustainable development remains an elusive (and perhaps unreachable) goal. Thus, the less ambitious strategy of simply seeking to make development more sustainable, might offer greater promise. Such an incremental (or gradient-based) method is more practical, because many unsustainable activities are often easier to recognize and eliminate.

Although the current state of knowledge makes it rather difficult to provide a complete definition of sustainomics, this paper has identified some of its key constituent elements and how they might fit together. The basic intention was to sketch out preliminary ideas which would help to stimulate discussion and encouraging further contributions that are needed to flesh out the initial framework.

The environmental, social and economic criteria for sustainability play an important role in the sustainomics framework. The environmental interpretation of sustainability focuses on the overall viability and health of ecological systems – defined in terms of a comprehensive, multiscale, dynamic, hierarchical measure of resilience, vigour and organization. Natural resource degradation, pollution and loss of biodiversity are detrimental because they increase vulnerability, undermine system health, and reduce resilience. The notion of a safe threshold (and the related concept of carrying capacity) are important – often to avoid catastrophic ecosystem collapse. The nested hierarchy of ecological and social systems across scales and their adaptive cycles constitute a 'panarchy'. A system at a given level is able to operate in its stable (sustainable) mode, because of the continuity provided by the slower and more conservative changes in the super-system above it, while being simultaneously invigorated and energized by the faster cycles of change taking place in the sub-systems below it.

Social sustainability seeks to reduce the vulnerability and maintain the health (i.e. resilience, vigour and organization) of social and cultural systems, and their ability to withstand shocks. Enhancing human capital (through education) and strengthening social values and institutions (like trust and behavioural norms) are key aspects. Weakening social values, institutions and equity will reduce the resilience of social systems and undermine governance. Preserving cultural diversity and cultural capital across the globe, strengthening social cohesion and networks of relationships, and reducing destructive conflicts, are integral elements of this approach. In summary, for both ecological and socioeconomic systems, the emphasis is on improving system health and their dynamic ability to adapt to change across a range of spatial and temporal scales, rather than the conservation of some 'ideal' static state.

The modern concept underlying economic sustainability seeks to maximize the flow of income that could be generated while at least maintaining the stock of assets (or capital), which yield these beneficial outputs. Economic efficiency plays a key role – in ensuring both efficient allocation of resources in production, and efficient consumption choices that maximize utility. Problems of interpretation arise in identifying the kinds of capital to be maintained (for example, manufactured, natural, human and social capital stocks have been identified) and their substitutability. Often, it is difficult to value these assets and the services they provide, particularly in the case of ecological and social resources. The issues of uncertainty, irreversibility and catastrophic collapse pose additional difficulties, in determining dynamically efficient development paths.

Equity and poverty play an important role in the sustainomics framework. Both issues have not only economic, but also social and environmental dimensions, and therefore, they need to be assessed using a more comprehensive set of indicators (rather than income distribution alone).

Several analytical techniques have sought to provide integrated and balanced treatment of the economic, social and environmental viewpoints. If material growth is the main issue, while uncertainty is not a serious problem, and relevant data are available, then the focus is more likely to be on optimizing economic output, subject to (secondary) constraints that ensure social and environmental sustainability. Alternatively, if sustainability is the primary objective, conditions are chaotic, and data are rather weak, then the emphasis would be on paths which are economically, socially and environmentally durable or resilient, but not necessarily growth optimizing. Sustainomics attempts to use both optimal and durable approaches, by developing their potential to yield consistent and complementary results. In the same vein, sustainomics could also better reconcile the natural science view which relies more on flows of energy and matter, with the sociological and economic approaches that focus on human activities and behaviour. One potential area of application of sustainomics involves integrated assessment models, which contain a variety of submodels that represent ecological, geophysical and socioeconomic systems. Cost-benefit analysis and multi-criteria analysis are useful tools for analysing sustainable development issues.

The sustainomics framework would encourage crucial changes in the mindset of decision-makers, by helping them to focus on the structure of development, rather than just the magnitude of economic growth (conventionally measured). This process would make development more sustainable, through the adoption of environmentally- and socially-friendly strategies that enable us to use natural resource inputs more frugally and efficiently, reduce polluting emissions, and facilitate public participation in social decisions. Sustainomics serves as an essential bridge between the traditional techniques of decision making and modern environmental and social analysis, by helping to incorporate ecological and social concerns into the decision making framework of human society. Operationally, it plays this bridging role by helping to map the results of environmental and social assessments (EA and SA) onto the framework of conventional economic analysis of projects. Thus, sustainomics identifies practical social and natural resource management options that facilitate sustainable development.

The paper also illustrates these concepts, by applying them to case studies involving energy problems across the full range of spatial scales. At the global-transnational level, the first case study examines the interplay of optimality and durability in determining appropriate global GHG emission target levels, while the second explores methods of combining efficiency and equity to facilitate South-North cooperation for climate change mitigation. At the level of national-economy policies, the third case study describes how the action impact matrix may be used for policy analysis, while the fourth sets out approaches for restructuring growth to make long term development more sustainable. On the subnational-sectoral scale, the fifth case outlines methods for improving energy sector decision making in Sri Lanka, and the sixth examines rainforest management in Madagascar. Finally, at the project-local level, multi-criteria analysis is applied to the case of a fuelwood stove project, and to compare small hydroelectric power projects, using relevant economic, social and environmental indicators.

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