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ENVIRONMENT AND ECONOMICS
WORKSHOP FOR JOURNALISTS

Appendix FIVE

"concepts and Case Studies for Making Development Sustainable"
By Dr. Mohan Munasinghe
Chapter 2

SUSTAINOMICS: A TRANSDISCIPLINARY FRAMEWORK FOR SUSTAINABLE DEVELOPMENT

2.1 Conceptual Framework

The world is currently exploring the concept of sustainable development or “development which lasts.” The goal is an approach that will (inter-alia) permit continuing improvements in the present quality of life at lower intensity of resource use, thereby leaving behind 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. While no universally acceptable practical definition of sustainable development exists, the concept has evolved to encompass three major points of view: economic, social and environmental, as shown in Figure 1 (see for example, Munasinghe 1993). Each viewpoint corresponds to a domain or system which has its own distinct driving force. The economy is geared mainly towards improving human welfare, primarily through increases in the consumption of goods and services. The environmental domain focuses on protecting the integrity and resilience of ecological systems and subsystems. The social system seeks to enrich human relationships and achieve individual and group aspirations.

**********Figure 1. Elements of Sustainable Development**********

2.1.1 Sustainomics -- Some Exploratory Ideas

As yet, there is no specific approach or framework which attempts to define, analyse, and implement sustainable development. Munasinghe (1994) proposed the term sustainomics to describe “a transdisciplinary, comprehensive, holistic, and balanced framework for making development more sustainable.” No single discipline could cope with the multiplicity of issues involved, and therefore a transdisciplinary framework is required which would address the many facets, from concept to actual practice. Thus, sustainomics would provide a broad and eclectic knowledge base to support sustainable development efforts (see Figure 2).

**********Figure 2. Sustainomics Knowledge Base Supports Sustainable Development**********

The sustainomics approach seeks to synthesize key elements drawn from traditional disciplines like ecology, economics, and sociology, as well as physics, chemistry, geology, botany, zoology, and anthropology. 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). Some areas of ecological science such as conservation ecology have proposed alternative approaches to the problems of sustainability (primarily relating to ecological systems) -- including the crucial concept of system resilience ((Holling 1973). Recent work in sociology has 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 like the first and second laws of thermodynamics (covering mass/energy balance and entropy, respectively), which yield valuable insights into how energy flows link physical, ecological and socioeconomic systems together (Georgescu-Roegen 1971; Odum and Odum 1981; Hall 1995). Recent work on the economics of sociology and environmental sociology are also relevant.

While building on such earlier work, sustainomics conjures up a more neutral image which focuses attention explicitly on sustainable development. 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 provide balanced treatment of the economic, social and environmental dimensions of sustainable development, but also holistically integrate all these elements (as well as related methodologies and paradigms) in a consistent manner. 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 environmental sustainability, whereas the need for continuing development, growth, equity and poverty alleviation are a priority for the South. Furthermore, the precise definition of sustainable development remains an elusive (and perhaps unreachable) goal. Thus, a less ambitious strategy which 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 recognise and eliminate.

This chapter seeks to identify some of the key constituent elements of sustainomics. The current state of knowledge makes it rather difficult to provide a comprehensive definition. The intention here is to sketch out several preliminary ideas which would serve as a starting point, in order to stimulate discussion that will help to flesh out the initial framework. The chapter also applies some of the concepts described below, to a topic of great contemporary significance - global climate change.

2.1.2 Traditional Growth and Development – Economic Focus

Current approaches to sustainable development draw on the experience of several decades of development efforts. Historically, the development of the industrialised world focused on material production. Not surprisingly, most industrialised 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 equity, below).

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 necessarily synonymous with material consumption (Ven. Rahula 1970). More recently, Maslow (1943) and others have identified hierarchies of needs which provide psychic satisfaction, beyond mere goods and services. Nevertheless, 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.

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 idealised, perfectly competitive economy is an important (Pareto optimal) benchmark, where efficient prices play a key role in both allocating productive resources to maximise output, and ensuring optimal consumption choices which maximise consumer utility. The well known cost-benefit criterion accepts all projects whose net benefits are positive (i.e., aggregate benefits exceed costs). 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 (monetised) welfare are fraught with difficulty -- both within and across nations, and over time (e.g., the value of human life).

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 quantity and quality of social interactions that underlie human existence. Institutional capital refers mainly to the formal laws as well as traditional or informal understandings that govern behaviour. Organisational capital is embodied in the entities (both individuals and social groups) which operate within these institutional arrangements. The level of mutual trust and extent of shared social norms help to determine the stock of social capital. 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. It implies that socio-political institutions will adapt to meet the challenges of modernisation, which often destroy traditional coping mechanisms that have evolved in the past (especially to protect disadvantaged groups).

Development in the environmental sense is a more 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 Mäler (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 prestigious *Journal of Economic Literature* mentions the role of natural resources only in the passing (Temple 1999).

### 2.1.3 Equitable Growth – Economic and Social Focus

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 directly improve income distribution. The development paradigm shifted towards equitable growth, where social (distributional) objectives, especially poverty alleviation, were recognised to be as important as economic efficiency, and distinct from the latter (see Box 2.1 for a brief review of equity-efficiency interactions).

************Box 2.1 Economic Efficiency and Social Equity**********

Equity is an ethical and usually people-oriented concept with primarily social, and some economic dimensions. It focuses on the basic fairness of both the processes and outcomes of decisionmaking. 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 alternative patterns of consumption which 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 decisionmaking, as well as by empowering disadvantaged groups (defined by income, gender, ethnicity, religion, caste, etc.) (Raymer 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).

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 short, both equity and poverty have not only economic, but also social and environmental dimensions, and in turn, they will need to be assessed using a more comprehensive set of indicators (rather than income distribution alone). An even broader 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).

### 2.1.4 Sustainable Development – Economic, Social and Environmental Focus

Protection of the environment has now become the third major objective of 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 impact assessments). Sustainability has emerged most strongly in the environmental context, but may be assessed also in economic and social terms (Munasinghe 1993). The environmental interpretation of sustainability focuses on the overall performance or health of ecological systems – defined in terms of a comprehensive, multiscale,
dynamic, hierarchical measure of resilience, vigour and organization (Costanza 1999). The classic definition of system resilience was provided by Holling (1973), in terms of the ability of an ecosystem to persist despite external shocks—where both the magnitude of the stress which the system can withstand, and the time to recovery, are key indicators. 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 2.2). 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 indicators of dynamism in an economic system. Organization depends on both complexity and structure of an ecological or biological system. For example, a multicellular organism like a human being is more highly organised than a single celled amoeba.

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 1992). 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 (see Box 2.2 for details).

Social sustainability is able to draw on the foregoing ideas, since habitats may be interpreted broadly to also include man-made environments like cities and villages (UNEP et al. 1991). Reducing 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. 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., decentralisation 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 their 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 2.2).

**********Box 2.2 Spatial and Temporal Aspects of 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 peoples’ 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). Such methods assume smoothly changing variables and are therefore rather inappropriate for analysing large changes and discontinuous phenomena. 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.

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 short to medium-run goal, 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 which are readily identifiable.

2.1.5 Consistent Integration of Economic, Social and Environmental Considerations

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 policymaking, since some of the most important decisions fall within the economic domain. While mainstream economics which is used for practical policymaking 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 emphasised. 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 optimising 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.

Optimality

The optimality-based approach has been widely used in economic analysis to generally maximise utility (or welfare), 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 Pezzezy (1992) and Islam (1998). Some ecological models also optimize variables like 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 (see Munasinghe 1993, for more details about valuation). More sophisticated economic optimisation 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 optimisation models.

Basically, any growth path characterised by non-decreasing stocks of assets (or capital) is sustainable -- the optimal one maximises economic growth as well. 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 maximising 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, optimisation and efficient use of resources may not be easily applied to ecological objectives like 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. Moreover, the price system (which has time lags) might fail to reliably anticipate 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 1998a). 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. Risk and uncertainty will also necessitate the
use of decision analysis tools.

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 which permit growth, but are not necessarily economically optimal. There is a greater willingness to trade off some economic optimality for the sake of greater safety, especially among increasingly risk-averse and vulnerable societies or individuals who face chaotic and unpredictable conditions -- in order to stay within critical environmental and social limits (see later discussion on the precautionary principle). 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 vulnerability or health (resilience, vigour and organization) of complex ecological and socio-economic systems. There is clear potential for interaction here due to linkages between the sustainability of social and ecological systems -- e.g., social disruption and conflict could exacerbate damage to ecosystems, and vice versa. In fact, long-standing social norms in many traditional societies have helped to protect the environment (Colding and Folke 1997).

Constraints based on sustainability could be represented also by the approach discussed earlier, that focuses on maintaining stocks of assets. This approach views the various forms of capital 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.

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 multi-dimensional in nature, comprehensive in scope, and account for spatial differences. A wide variety are described already in the literature (Liverman et al. 1988, Kuik and Verbruggen 1991, Opschoor and Reijnders 1991, Holmberg and Karlsson 1992, Adriaanse 1993, Alfsen and Saeba 1993, Bergstrom 1993, Gilbert and Feenstra 1994, Moffat 1994, OECD 1994, Munasinghe and Shearer 1995, Azar et al. 1996, UN 1996, CSD 1998; UNDP 1998; World Bank 1997, 1998a).

Measuring economic, environmental (natural), human and social capital also raises various problems. Manufactured capital may be estimated using conventional neoclassical economic 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, sulphur 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., see Chapter 3, Freeman 1993, Munasinghe 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 which is most difficult to assess (Grootaert 1998). Putnam (1993) described it as “horizontal associations” among people, or social networks and associated behavioral 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), that 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.

Complementarity and Convergence of Approaches

National economic management often provides good examples of how the two approaches complement one another. For example, economywide policies involving both fiscal and monetary measures (e.g., taxes, subsidies, interest rates and foreign exchange rates) might be optimised on the basis of quantitative
macroeconomic models. Nevertheless, decisionmakers inevitably modify these economically “optimal” policies to take into account other sociopolitical considerations (such as protection of the poor, regional factors, etc.), before implementing them.

The determination of an appropriate target trajectory for future global GHG emissions (and corresponding target GHG concentration) provides another useful illustration of these two approaches (for details, see IPCC 1996c or Munasinghe 1998a). Under an economic optimising framework, the ideal solution would be to first estimate the long-run marginal abatement costs (MAC) and the marginal avoided damages (MAD) associated with different GHG emission profiles -- see Figure 3(c), where the error bars on the curves indicate measurement uncertainties. 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) equal or just exceed the corresponding costs (of mitigation measures required to reduce that unit of GHG emissions), i.e., MAC = MAD at point $R_{op}$.

***********Figure 3. Determining Mitigation Targets***********

Durable strategies become more relevant when we recognise that MAC and/or MAD might be poorly quantified and uncertain. Figure 3(b) assumes that MAC is better defined than MAD. First, MAC is determined using techno-economic least cost analysis -- an optimising 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 3(a) 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.

It would be useful to explore the potential for convergence of the optimising and durability approaches, in practice. First, this implies that 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 utilised 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 minimised by moving from linear throughput to 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, both inter- and intra-generational equity (especially poverty alleviation), pluralistic and consultative decisionmaking, 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 minimised (see also the discussion below on “tunneling” and “leapfrogging”). Reducing $[Y/Q]$ implies “social decoupling” (or “dematerialisation”) 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 “decarbonisation”) 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.

Multi-criteria Analysis (MCA)
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 (see Chapter AAA for details). The resulting costs and benefits are combined into a single decisionmaking criterion like net present value (NPV) or the internal rate of return (IRR). However, it is often very difficult to value environmental and social impacts (and even certain economic outcomes). Consequently, such impacts may be ignored in the conventional CBA methodology, which would tend to favour the neoclassical economic viewpoint -- although environmental and social considerations might be introduced in the form of side constraints.

Multi-criteria analysis (MCA) or multi-objective decisionmaking is particularly useful in situations when a single criteria approach like cost-benefit analysis falls short (e.g., due to problems in valuing environmental impacts like bio-diversity loss). 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 4 is a two dimensional representation of the basic concepts underlying MCA. Consider an electricity supplying firm which 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 and C 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.

**************Figure 4. Making Balanced Tradeoffs with Multi-criteria Analysis**************

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 the figure). The preferred alternative is one which yields the greatest utility -- i.e., at the point of tangency D of the best equi-preference curve, with the trade-off curve.

Since such 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 CMAX in the figure. Similarly, ecological experts might set a maximum value of biodiversity loss BMAX (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 CMAX 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 ecosystem. In a more practical sense, CMAX and BMAX 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 the figure.

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 \( Z_i \).

2.2. Towards an Applications Framework

2.2.1 Restructuring Development and Growth For Greater Sustainability
One key aspect to keep in mind is the fact that 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. Figure 5 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 the figure 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 5. The Socioeconomic Subsystem Embedded in the Larger Ecosystem**********

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. As illustrated earlier in Figure 5, 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 6 summarizes the modern approach which 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 6. Restructuring Development and Growth**********

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 which promote environmentally- and socially-friendly technologies that use natural resource inputs more frugally and efficiently, reduce polluting emissions, and facilitate public participation in decisionmaking, 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. If properly managed, IT could also make development more socially sustainable, by improving access to information, increasing public participation in decisionmaking, and empowering disadvantaged groups. The correct blend of market forces and regulatory safeguards are required.

2.2.2 Linking Sustainable Development Issues with Conventional Decisionmaking

Role of Sustainomics

Sustainomics helps in identifying practical social and natural resource management options that facilitate sustainable development. It serves as an essential bridge between the traditional techniques of decisionmaking and modern environmental and social analysis, by helping to incorporate ecological and social concerns into the policy framework of human society, as shown in Figure 7.

*********Figure 7. Incorporating Sustainable Development Concerns Into Decisionmaking**********
The right-hand side of the diagram indicates the hierarchical nature of conventional decisionmaking in a modern society. The global and transnational level consists of sovereign nation states. In the next level are individual countries, each having a multisected macroeconomy. Various economic sectors (like industry and agriculture) exist in each country. Finally, each sector consists of different subsectors and projects. The usual decisionmaking process on the right side of Figure 7 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.

Unfortunately, environmental and social analysis cannot be carried out readily using the above decisionmaking 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 7 shows one convenient environmental breakdown in which the issues are: (1) global and transnational (e.g., climate change, ozone layer depletion); (2) natural habitat (e.g., forests and other ecosystems); (3) land (e.g., agricultural zone); (4) water resource (e.g., river basin, aquifer, watershed); and (5) urban-industrial (e.g., metropolitan area, airshed) -- related. 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 impact assessment (EIA) have been developed to facilitate this difficult analysis. 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 7 also shows how sustainomics could play its bridging role at the ecology-economy interface, by mapping the EIA results 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 economywide level), and global/transnational environmental economic analysis (at the international level), facilitate this process of incorporating environmental issues into traditional decisionmaking. Since there is considerable overlap among the analytical techniques described above, this conceptual categorization should not be interpreted too rigidly.

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 impact assessment (SIA) at the society-economy interface, in order to incorporate social considerations more effectively into the economic decisionmaking framework.

3. Climate Change and Sustainable Development

The climate change problem fits in quite readily within the rather broad conceptual framework for sustainomics, described above. Decisionmakers 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 -- in relation to the economic, social and environmental dimensions of sustainable development. Some of the potential linkages, and the sustainomics-related principles and concepts that apply in this context, are outlined below.

3.1 General Economic Development
First, global warming poses a significant potential threat to future development activities and the 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 earlier, this target level is defined at the point $MAC = MAD$. The underlying principles are based on optimality and the economically efficient use of a scarce resource, i.e., the global atmosphere.

When considering climate change response options, several ideas and principles which are widely used in environmental economics analysis would be useful -- these include the polluter pays principle, economic valuation, internalisation 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 internalised by imposing costs on polluters that reflect the damage caused. The theoretical basis for this is well known since Pigou (1932) originally defined and treated externalities in rigorous fashion -- in terms of the economic impact of the actions of one agent on another, without any corresponding (compensatory) financial exchange. In this context, the notion of property rights is also relevant to establish that the atmosphere is a valuable and scarce resource which cannot be used freely and indiscriminately.

### 3.2 Social Equity

Second, climate change could also undermine social welfare and equity in an unprecedented manner. In particular, both intra- and inter-generational equity are likely to be worsened (IPCC 1996c). 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. Some of the impacts of recent large scale disasters like El Nino might provide useful case study material. 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 tons per year while permitting a corresponding level in the north of over 3 tons per year will not facilitate the co-operation of developing countries, and therefore is unlikely to be durable (see also Chapter XXX). More generally, inequity could undermine social cohesion and exacerbate conflicts over scarce resources.

One starting point is the principle 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: (a) the establishment of an equitable and participative global framework for making and implementing collective decisions about climate change; (b) reducing the potential for social disruption and conflicts arising from climate change impacts; and (c) protection of threatened cultures and preservation of cultural diversity. The polluter pays principle (mentioned earlier) is based not only on economic efficiency, but also on equity and 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). 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 (Squire and Van der Tak 1975). 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 maximisation 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, 1995).
Some social equity and economic efficiency interactions are discussed in Box 2.1.

3.3 **Sustainability**

Third, the sustainability viewpoint draws attention to the fact that increasing anthropogenic emissions and accumulations of GHGs might significantly perturb a critical global subsystem -- the atmosphere (UNFCCC 1992). Sustainability will depend on several factors, including: (1) climate change intensity (e.g., magnitude and frequency of shocks); (2) system vulnerability (e.g., extent of impact damage); and (3) system resilience (i.e., ability to recover from impacts). Changes in the global climate (e.g., mean temperature, precipitation, etc.) could well threaten the stability of a range of critical physical, ecological and social systems and subsystems (IPCC 1996b). More attention may need 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 which 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.

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 which 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 1992).

4. **Incorporating Climate Change Strategies into Conventional Decisionmaking**

As seen in the previous section, climate change is likely to undermine the sustainability of future development. Thus, it would be useful to explore the linkages between climate change and sustainable development.

4.1 **Moving From the Project Level to Macropolicy Impacts**

The procedures for conventional environmental and social impact assessment at the project/local level (which are now well-accepted world wide), may be readily adapted to assess the effects of micro-level activities on GHG gas emissions (World Bank 1998b). 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). Box 2.3 illustrates how an MCA-based analysis at the project level, could provide balanced treatment of economic, social and environmental considerations. The project evaluated involves the case of an improved fuelwood burning stove.

**********Box 2.3 Multicriteria Analysis of a Fuelwood Stove Project**********

Conventional economic valuation of environmental impacts is a key step in incorporating the results of project level environmental impact assessment into economic decisionmaking -- e.g., cost-benefit analysis (see also Chapter XXX). 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 (UNSO 1993, Atkinson et al. 1997, World Bank 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. Costanza (1999) seeks to broaden the definition of valuation to include: (1) efficiency based values (conventional economic willingness-to-pay); (2) fairness based values (which capture community or social preferences); and (3) sustainability based values (that are related to contributions to systemwide and global functions).

At the same time, national policymakers routinely make many key macro-level decisions that could have (often inadvertent) impacts on both climate change mitigation and adaptation, which are far more significant than the effects of local economic activities. These pervasive and powerful measures are aimed at addressing economic development, environmental sustainability and social equity issues -- which invariably have much higher priority in national agendas, than climate change. For example, many macroeconomic policies seek to induce rapid growth, which in turn could potentially result in greater levels of GHG emissions, or increase vulnerability to the future impacts of climate change. More attention needs to be paid to such economywide policies, whose environmental and social linkages have not been adequately explored in the past.

Clearly, climate change strategies and policies that are consistent with other national development measures, 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 make local and national development more sustainable, but also enhance climate change adaptation and mitigation efforts. Such policies could help to build support for climate change strategies among the traditional decisionmaking community, and conversely make climate change specialists more sensitive to sustainable development 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 global environment.

4.2. National Economywide Policies

Scope of Policies

The most powerful economic management tools currently in common use are economywide reforms, which include structural adjustment packages (see Chapter XXX for details). Economywide (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 programs (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 liberalisation, privatisation, and similar programs. Since space limitations preclude a comprehensive review of interactions between economywide policies and climate change, we briefly examine several examples which provide a flavour of the possibilities involved (for details, see Munasinghe 1997; Jepma and Munasinghe 1998).

Range of Impacts

On the positive side, liberalising 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 GHG emitted (i.e., so called “win-win” outcomes). For example, reforms which improve the efficiency of energy use could reduce economic waste and lower the intensity of GHG emissions. Similarly, improving property rights and strengthening incentives for better land management not only yields economic gains but also reduces deforestation of open access lands (e.g., due to “slash and burn” agriculture).

At the same time, growth inducing economywide policies could lead to increased GHG emissions, unless the macro-reforms are complemented by additional environmental and social measures. Such negative impacts on climate change are invariably unintended and occur when some broad policy changes are undertaken while other hidden or neglected economic and institutional imperfections persist. 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. 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 net GHG emissions while enhancing macroeconomic gains. Countrywide policies could also influence adaptation, 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 (Munasinghe 1997). As explained in Chapter XXX, such a matrix could help to promote an integrated view, by meshing development and climate related decisions with priority economic, environmental and social issues.

4.3. Restructuring Growth

Economic growth continues to be a widely pursued objective of most governments, and therefore, reducing the intensity of GHG emissions of human activities is an important step in mitigating climate change. Given that the majority of the world population lives under conditions of absolute poverty (e.g., over 3 billion persons subsist on less than USD1 per day), a climate change strategy that did not unduly constrain growth prospects in those areas would be more attractive. A sustainomics based approach would seek to identify measures that modify the structure of development and growth (rather than restricting it), so that GHG emissions are mitigated and adaptation options enhanced.

The above approach is illustrated in Figure 8, 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 industrialised countries along CE.

**********Figure 8. Environmental Risk Versus Development Level**********

As outlined in Section 4.1, 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 the figure (Munasinghe 1997). Thus, the emphasis is on identifying policies that will help delink carbon emissions and growth, with the curve in Figure 8 serving mainly as a useful metaphor or organizing framework for policy analysis.

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 8 could be caused by economic imperfections which make private decisions deviate from socially optimal ones (Munasinghe 1998b). Thus the adoption of corrective policies that reduce such divergences and thereby reduce GHG emissions per unit of output, would facilitate movement along the lower path ABD. From the durability viewpoint, reducing the higher level 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 8).

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 (Holz-Eakin and Selden 1995; Sengupta 1996, Moomaw and Urruh 1997; Cole et al. 1997). One reported outcome is an inverted U-shape (called the environmental Kuznet's curve or EKC) - like the curve ABCE in the figure. In this case, the more socially optimal path BDE could be viewed as a sustainable development “tunnel” through the EKC (Mumasinghe 1995).

5. Summary and Concluding Thoughts

Sustainable development is one of the most important challenges facing humankind, at the turn of the century. While no universally acceptable practical definition of SD 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 force. 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 protecting the integrity and resilience of ecological systems and subsystems. 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 transdisciplinary comprehensive, holistic, and balanced framework for making development more sustainable.” It seeks to synthesize key elements from traditional disciplines like ecology, economics, and sociology, as well as physics, chemistry, geology botany, zoology, anthropology, and engineering. 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, economics of sociology and environmental sociology. While building on earlier work, sustainomics constitutes a more neutral expression which focuses attention explicitly on sustainable development.

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 transdisciplinary 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.

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 performance or 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.

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.

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 is available, then the focus is more likely to be on optimising economic output, subject to (secondary) constraints that ensure social and environmental sustainability. Alternatively, if sustainability is the primary objective, conditions are chaotic, and data is rather weak, then the emphasis would be on paths which are economically, socially and environmentally durable or resilient, but not necessarily growth optimising. 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.

The sustainomics framework would encourage crucial changes in the mindset of decisionmakers, 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 decisionmaking and modern environmental and social analysis, by helping to incorporate ecological and social concerns into the decisionmaking framework of human society. Operationally, it plays this bridging role by helping to map the results of environmental and social impact assessments (EIA and SIA) onto the framework of conventional economic analysis of projects. Thus, sustainomics identifies practical social and natural resource management options that facilitate sustainable development.

Global climate change (GCC) also poses an unprecedented challenge to humanity, and the application of the sustainomics approach to climate change would help to elucidate the concepts and issues involved, and identify and fill in gaps. While climate change is an important long term problem, it is crucial to recognize also that (especially for the developing countries), there are a number of other priorities that affect human welfare more immediately -- such as hunger and malnutrition, poverty, health, local environmental damage, and social conflicts. In this context, predictions about climate change, its impacts, and the costs of mitigation are important for the policymaking dimension, because climate change issues reside within broader questions about sustainable development.

Clearly, GCC issues must be examined in relation to the three main elements of sustainable development (economic, social and environmental). First, future economic development and the well being of large numbers of human beings would be threatened by global warming. In its simplest from, the economic efficiency viewpoint seeks to maximize the net benefits (or outputs of goods and services) from the use of the global resource represented by the atmosphere. When considering climate change response options, several ideas and principles which are widely used in environmental economics analysis would be useful -- including the polluter pays principle, economic valuation, internalisation of externalities, and property rights. The polluter pays principle argues that those who are responsible for damaging emissions should pay the corresponding costs, thus providing an incentive for polluters to reduce their emissions to optimal (i.e., economically efficient) levels. Quantification and economic valuation of potential damage from polluting emissions is an important prerequisite. The notion of property rights is also relevant to establish that the atmosphere is a valuable and scarce common property resource which cannot be used freely and indiscriminately.

Second, social welfare and equity would also be undermined in an unprecedented manner, by climate change. In particular, both intra- and inter-generational equity are likely to be worsened, especially since poorer nations and disadvantaged groups within nations are more vulnerable, and the costs of damage, as well as of necessary adaptation and mitigation efforts will be unevenly distributed. Sustainomics suggests that inequitable distributions are not only ethically unappealing, but also likely to be unsustainable in the long run, because they undermine social cohesion and exacerbate conflicts over scarce resources. In identifying response strategies, one starting point is the ethical viewpoint 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: (a) the establishment of an equitable and participative global framework for making and implementing collective decisions about climate change; (b) reducing the potential for social disruption and conflicts arising from climate change impacts; and (c) protection of threatened cultures and preservation of cultural diversity. The polluter pays principle (mentioned earlier) is based not only on economic efficiency, but also on equity and 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).

Third, the environmental sustainability viewpoint draws attention to the fact that increasing anthropogenic emissions and accumulations of GHGs might significantly perturb a critical global subsystem -- the atmosphere. Changes in the global climate are likely to threaten the stability of a range of critical physical, ecological and socioeconomic systems and subsystems. More attention also needs to be paid to the erosion of social capital (i.e., the basic glue that binds communities together), and increasing vulnerability of social values and institutions which are already stressed due to rapid technological changes. Sustainomics draws on several concepts from contemporary environmental and social analysis to guide the development of 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). It is considered important to avoid irreversible damage to bio-geophysical systems and prevent major disruption of socioeconomic systems. Finally, the precautionary principle argues that lack of scientific certainty about climate change effects should not become a basis for inaction.

Unfortunately, our understanding of the chain of causality from emissions of GHGs to ultimate impacts on natural and human systems, is hampered by the large spatial and temporal scale of events, their complexity and irreversibility, and the risks of non-linear responses and catastrophic collapse. Both scientific uncertainty arising from lack of knowledge about natural systems, and socioeconomic and technological uncertainty associated with human systems, are difficult to deal with. Furthermore, equity issues occur in many forms, e.g., both decisionmaking procedures and their consequences must be equitable to all stakeholders. Intragenerational equity involves tradeoffs among affected groups, especially between the richer and poorer nations. Intergenerational equity also requires a balance between the rights of current and future generations, with the discount rate playing a key role.

Climate change strategy needs to be harmonised with sustainable development policies, especially the powerful economywide reforms in common use -- including both sectoral and macroeconomic adjustment policies which have widespread effects throughout the economy. Clearly, climate change strategies that are consistent with other national development policies, will tend to be more effective than isolated technological or policy options. In particular, the highest priority needs to be given to finding “win-win policies” which not only make local and national development more sustainable, but also enhance climate change adaptation and mitigation efforts, i.e., they promote all three elements of sustainable development (economic, social and environmental). They would reduce the potential for conflict between two powerful current trends -- the growth oriented, market based economic reform process, and protection of the global environment. For example, liberalising policies such as the removal of price distortions (especially energy subsidies), and promotion of market incentives, have the potential to improve economic growth rates, while increasing the value of output per unit of GHG emitted (i.e., a “win-win” outcome).

Policies and measures which advance one objective at the expense of another need to be analysed within a framework that facilitates trade-offs (e.g., actions which increase manufactured capital while depleting both social and natural capital; or improve the resilience of a social system while increasing the vulnerability of an ecosystem). In the case of climate change, economywide policies which successfully induce growth, could also lead to increased GHG emissions, unless the macro-reforms are complemented by additional environmental and social measures. Such negative impacts on climate change are invariably unintended and occur when some broad policy changes are undertaken while other hidden or neglected economic and institutional imperfections persist. In general, the remedy does not require reversal of the original reforms, but rather the implementation of additional complementary measures that mitigate climate change.

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, which helps to promote an integrated view, by meshing development and climate related decisions with priority economic, environmental and social issues. When all important impacts of a specific climate change option may be valued in economic terms, the usual approach of comparing the corresponding costs and benefits will provide useful insights. Where certain critical impacts cannot be valued (i.e., reduced to a single monetary “numeraire”), other techniques such as multicriteria analysis could be helpful. High levels of uncertainty and risk need to be dealt with through the use of modern decision analysis frameworks.

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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 maximisation 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 appropriate 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 recognised that all decisionmaking 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 (CBA) based on economic efficiency (which seek 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 maximising GNP, and establishing institutions and processes charged with redistribution, social protection, and provision of various social goods to meet basic needs.
An operationally useful concept of sustainability must refer to the persistence, viability and resilience of organic or biological systems, over their "normal" life span. In this ecological context, sustainability is linked with both spatial and temporal scales, as shown in the figure. 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 meter, respectively. The diagonal band shows the expected or "normal" range of lifespans for a nested hierarchy of living systems 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 super-system (such as single cells within a multi-cellular organism) generally has a shorter life span than the super-system itself. If subsystem lifespans increase too much, the encompassing super-system is likely to lose its plasticity and become "brittle" -- as indicated by the region below and to the right of the normal range (Holling 1992). In other words, it is the timely death and replacement of subsystems that facilitates successful adaptation, resilience and evolution of larger systems.

Holling (1973) defined resilience in terms of the ability of an ecosystem to persist despite external shocks, while Petersen et al. (1998) argued further that the resilience of a given ecosystem depends on the continuity of ecological processes at both larger and smaller scales.

We may summarize the foregoing by arguing that sustainability requires biological systems to be able to enjoy a normal life span and function normally, within the range indicated in the figure. 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 context, extended longevity involving a greater than normal life-span would not be a matter for particular concern. On
the practical side, forecasting up to a time scale 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 decisionmakers 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 behavior using low cost measures, while studying the issue more carefully.
Multi-criteria analysis 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 monetarily. As shown in the above figure, 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 of 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 labor 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 green house emissions resulting from inefficient combustion.

After realizing such "win-win" gains, other available options would require tradeoffs. In triangle GIH, further environmental and social gains are attainable only at the expense of sharply increasing costs. For example, shifting from fuelwood to 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.

A recent study of power system planning in Sri Lanka has demonstrated the versatility and balance inherent in the MCA approach (Meier and Munasinghe 1994). In this case, end-use energy efficiency and demand side management measures including fluorescent lighting, high efficiency electric motors, and pricing policy, provided "win-win" options. They proved superior to all other alternatives (e.g., supply options such as hydroelectricity, oil- and coal-fired generating plants), in relation to three key attributes -- a social indicator based on the effects of air quality on human health, an environmental indicator based on an index of biodiversity loss, and an economic indicator measured by monetary costs. Conversely, several prominent hydropower projects were excluded because they performed poorly in terms of both biodiversity loss and economic costs.
Figure 1. Elements of Sustainable Development

- Economic
  - Growth
  - Efficiency
  - Stability

- Environmental
  - Valuation
  - Internalization

- Social
  - Intra-generational Equity
  - Consultation/Empowerment
  - Poverty Reduction

- Intra-generational Equity
- Natural Resources
- Resilience

Source: M. Munasinghe (1993)
Figure 2. Sustainomics Knowledge Base Supports Sustainable Development
Figure 3. Determining abatement targets: (a) absolute standard; (b) affordable safety minimum standard; (c) cost-benefit optimum

Source: Adapted from IPCC 1996c, Figure 5.10
Figure 4. Simple Two-Dimensional Example of Multi-criteria Analysis.
Figure 5. The ecosystem capacity may become overloaded by the growing socioeconomic subsystem (broken lines).
Figure 6. Restructuring Development to Make Growth More Sustainable

Ecosystem

Socioeconomic Subsystem

Unsustainable

Sustainable

Ecosystem

Socioeconomic Subsystem
Figure 7. Incorporating Environmental Concerns Into Decisionmaking

- **Global**
  - Transnational
  - Natural Habitats
  - Land
  - Water
  - Urban, Indust., and Air

- **Physical, Biological and Social Impacts**

- **Sustainomics**
  - Environment-Economy Interface
  - Integrated Resource Management
  - Valuation

- **Conventional Economic Analysis**
  - Impact
  - Cost-Benefit Analysis

- **Techno-Engineering Financial Analysis**

- **Inter-National**
  - National Macroecon.
  - Sectoral
  - Regional
  - Subsectoral
  - Project
Figure 8. Environmental Risk versus Development Level