1. INTRODUCTION

The wide ranging potential impacts of climate change on sustainable development and vice versa, suggest that the linkages between these two topics need to be critically analysed. Such an analysis was attempted in the IPCC third assessment report (TAR), and while some progress was made, the work was incomplete. This paper summarizes key lessons from the TAR and relevant post-TAR findings, as a starting point for preparations for the fourth assessment report (AR4). Results are presented within a transdisciplinary integrative framework (sustainomics), which is applied to the nexus of sustainable development and climate change.

The global development community is looking for new solutions to traditional development issues such as economic stagnation, persistent poverty, hunger, malnutrition, and illness, as well as newer challenges like environmental degradation and globalisation. One key approach that has received growing attention is the concept of sustainable development or ‘development which lasts’ (WCED 1987). Following the 1992 Earth Summit in Rio de Janeiro and the adoption of the United Nations’ Agenda 21, the goal of sustainable development has become well accepted world-wide (UN 1993).

Meanwhile, the threat of global climate change poses an unprecedented challenge to humanity. While climate change is important in the long run, it is crucial to recognise that (especially for the developing countries) there are a number of other development issues that affect human welfare more immediately – such as hunger and malnutrition, poverty, health, and pressing local environmental issues. Climate change and sustainable development interact in a circular fashion. Climate change will have an impact on prospects for sustainable development, and in turn, alternative development paths will certainly affect future climate change. Seen from the development viewpoint, climate change vulnerability, impacts and adaptation are the main elements of concern. From the climate perspective, development pathways also determine emission levels, and they have implications for mitigation strategies as well.

In this context, many relevant findings emerged from the IPCC TAR process, as documented in the three working group reports, special reports, and other documents like the guidance paper on development, equity and sustainability and proceedings of two expert meetings on climate change and sustainable development. These results may be grouped into the following categories (see Annex 1 for details):
1. Conceptual overview of linkages between climate change and sustainable development.
2. Consequences of climate change impacts for sustainable development prospects, in various sectors, systems, and regions.
3. Consequences of climate change response actions (mitigation, adaptation, and vulnerability reduction) for sustainable development prospects in various sectors, systems, and regions.
4. Synergies and tradeoffs between different sustainable development strategies, and options for increasing adaptive capacity and reducing vulnerability to climate change, in various sectors, systems and regions.
5. Synergies and tradeoffs between different sustainable development strategies, and options for increasing mitigative capacity and mitigating GHG emissions, in various sectors, systems and regions.
6. Mutual interlinkages between different overall development paths (that cut across various sectors and systems), including strategies for technology development, diffusion and transfer processes, and climate change responses.

This paper addresses the same basic issues within a more systematic framework. It is organised as follows. Section 2 introduces sustainomics as a transdisciplinary framework for making development more sustainable. Section 3 links sustainable development and climate change. In section 4, tools and methods of integrating and analysing the social, economic, and environmental dimensions of this nexus are briefly presented. These ideas are illustrated in section 5, by applying them to specific examples involving climate-related problems across the full range of spatial scales -- at the global, national-economy-wide, sub-national-sectoral, and local-project levels. Section 6 contains some concluding thoughts and implications.

2. OVERVIEW OF KEY CONCEPTS

2.1 Sustainomics and sustainable development concepts

The multiplicity and complexity of issues involved in sustainable development cannot be covered by a single discipline. Munasinghe (1992, 1994) proposed the term sustainomics to describe “a transdisciplinary, integrative, comprehensive, balanced, heuristic and practical meta-framework for making development more sustainable” (see Box 1 for details). Sustainomics accepts that the precise definition of sustainable development remains an ideal, elusive (and perhaps unreachable) goal. A less ambitious, but more focused and feasible strategy would merely seek to ‘make development more sustainable’. Such an incremental (or gradient-based) method is more practical, because many unsustainable activities can be recognised and eliminated. This approach seeks continuing improvements in the present quality of life at a lower intensity of resource use, and aims to leave behind for future generations an undiminished stock of productive assets -- manufactured, natural and social capital -- that will enhance opportunities for improving their quality of life (Munasinghe 1992). The current state of knowledge is
inadequate to provide a comprehensive definition of sustainomics, but we are learning about some of its key constituent elements, and how they might fit together. Starting from such an initial approach, sustainomics is emerging as a heuristic, dynamically evolving framework that could address rapidly changing sustainable development and climate change issues, in a practical manner.

Key elements of sustainomics relevant to climate change are outlined in this paper as follows. Issues are analysed first through the prism of the sustainable development triangle -- from the economic, social and environmental viewpoints. Integrated analysis is facilitated by a joint optimality-durability approach. Development and growth may be restructured more sustainably, using a “tunneling” perspective that internalizes externalities. Sustainable development assessments (SDA) are important, especially at the sub-national and project levels. A mapping model facilitates the implementation of SDA, by incorporating environmental and social assessments (EA and SA) into the conventional economic decision making process, with economic valuation of environmental and social impacts serving as the bridge to cost-benefit analysis. Multi-criteria analysis (MCA) plays a key role in making trade-offs among diverse objectives, especially when economic valuation is difficult. The Action Impact Matrix (AIM) approach and comprehensive, multi-sector models (e.g., computable general equilibrium or CGE models) based on an expanded set of national accounts helps integrate economic, social and environmental issues at the macroeconomic decision making level. Integrated assessment models (IAMs) play a key role in analyzing global level problems, such as climate change. A range of sustainable development indicators help to measure progress and make choices at various levels of aggregation.

Munasinghe (1992, 1994) proposed the term sustainomics to describe “a transdisciplinary, integrative, comprehensive, balanced, heuristic and practical meta-framework for making development more sustainable”, to remedy the lack of a specific approach or practical framework that attempts to define, analyse, and implement sustainable development. Hitherto, multidisciplinary approaches involving teams of specialists from different disciplines have been applied to complex sustainable development issues. A step further has also been taken through interdisciplinary work, which seeks to break down the barriers among various disciplines. However, what is now required is a truly transdisciplinary meta-framework, which would weave the knowledge from existing disciplines into new concepts and methods that could address the many facets of sustainable development – from concept to actual practice. As shown in Figure 1(b), sustainomics would provide a comprehensive and eclectic knowledge base to support sustainable development efforts.

The sustainomics approach seeks to synthesize a ‘science of sustainable development’ which integrates knowledge from both the sustainability and development domains. Such a synthesis will need to draw on a wide range of core disciplines from the physical, social and technological sciences. 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). Sustainomics is also related to recent initiatives on a ‘sustainability transition’ and ‘sustainability science’ (Clark 2000, Parris and Kates 2001, Tellus Inst. 2001). Newer areas of ecological science such as conservation ecology, ecosystem management and political ecology have birthed alternative approaches to the problems of sustainability, including crucial concepts like system resilience, and integrated analysis of ecosystems and human actors (Holling 1992). Recent papers in sociology have explored ideas about the integrative glue that binds societies together, while drawing attention to the concept of social capital and the importance of social inclusion (Putnam 1993). The literature on energetics and energy economics has focused on the relevance of physical laws like the first and second laws of thermodynamics (covering mass/energy balance and entropy, respectively). This research has yielded valuable insights into how energy flows link physical, ecological and socioeconomic systems together, and analysed the limits placed on ecological and socioeconomic processes by laws governing the transformation of ‘more available’ (low entropy) to ‘less available’ (high entropy) energy (Georgescu-Roegen 1971; Munasinghe 1990; Hall 1995). Recent work on sociological economics, environmental sociology, cultural economics, economics of sociology, and sociology of the environment, are also relevant. The literature on environmental ethics has explored many issues including the weights to be attached to values and human motivations, decision making processes, consequences of decisions, intra- and inter-generational equity, the ‘rights’ of animals and the rest of nature, and human responsibility for the stewardship of the environment (Andersen 1993; Environmental Ethics; Sen 1987; Westra 1994).

While seeking to build on such earlier work, sustainomics projects a more neutral image. The neologism is necessary to focus attention explicitly on sustainable development, and avoid the implication of any disciplinary bias or hegemony. For example, both biology and sociology can provide important insights into human behaviour, which challenge the ‘rational actor’ assumptions of neoclassical economics. Thus, recent studies seek to explain phenomena such as hyperbolic discounting (versus the more conventional exponential discounting), reciprocity, and altruistic responses (as opposed to selfish, individualistic behaviour) (Gintis 2000, Robson 2001). In the same vein, Siebhuner (2000) has sought to define ‘homo sustinens’ as a moral, cooperative individual with social, emotional and nature-related skills, as opposed to the conventional ‘homo economicus’ motivated primarily by economic self interest and competitive instincts.

The substantive trans-disciplinary framework underlying sustainomics leads to the balanced and consistent treatment of the economic, social and environmental dimensions of sustainable development (as well as other relevant disciplines and paradigms). Balance is also needed in the relative emphasis placed on traditional development versus sustainability. For example, much of the mainstream literature on sustainable development which originates in the North tends to focus on pollution, the unsustainability of growth, and population increase. These ideas have far less resonance
in the South, whose priorities include continuing development, consumption and growth, poverty alleviation, and equity.

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

While many attempts have been made to define sustainable development, one widely accepted and useful concept that has evolved encompasses three major points of view: economic, social and environmental [Figure 1(a)]. Each viewpoint corresponds to a domain (and a system) that has its own distinct driving forces and objectives. The economy is geared mainly towards improving human welfare, primarily through increases in the consumption of goods and services. The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social domain emphasises the enrichment of human relationships, achievement of individual and group aspirations, and strengthening of values and institutions.

Figure 1(b) indicates how an emerging ‘sustainomics’ framework (i.e., science of sustainable development), and associated trans-disciplinary knowledge base, would support comprehensive and balanced assessment of the trade-offs and synergies that might exist between the economic, social and environmental dimensions of sustainable development (as well as other relevant disciplines and paradigms) (Munasinghe 1994, 2001; OECD 2001). Balance is also needed in the relative emphasis placed on traditional development (which is more appealing to the South) versus sustainability (which is emphasised by the North) (Munasinghe1992).

Current approaches to sustainable development draw on the development experience of the 20th century. For example, the dominant development paradigm during the 1950s was growth, focusing mainly on increasing economic output and consumption. In the 1960s, development thinking shifted towards equitable growth, where social (distributional) objectives, especially poverty alleviation, were recognized to be as important as economic efficiency. Since the 1970s, environment has emerged as the third key element of (sustainable) development.
One (among many) broad descriptions, defines sustainable development as “a process for improving the range of opportunities that will enable individual human beings and communities to achieve their aspirations and full potential over a sustained period of time, while maintaining the resilience of economic, social and environmental systems” (Munasinghe 1994). Thus, sustainable development requires (i) opportunities for improving economic, social and ecological systems; and (ii) increases in adaptive capacity (Gunderson and Holling 2001). Expanding the set of opportunities for system improvement will give rise to development, while increasing adaptive capacity will improve resilience and sustainability. The evolving behaviour of individuals and communities facilitates learning, the testing of new processes, adaptation, and improvement.

2.2 Economic Domain

Welfare (or utility) – measured as willingness to pay for goods and services consumed – is the widely used benchmark of economic progress. 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. Nevertheless, the equation of welfare with monetary income and material consumption has also been challenged for centuries, while more
recently, Maslow (1970) and others have identified hierarchies of needs that provide psychic satisfaction, beyond mere goods and services.

Pareto optimality is considered the goal of economic efficiency. It favours actions that will improve the welfare of at least one individual without worsening the situation of anyone else. The idealized, perfectly competitive economy is an important (Pareto optimal) benchmark. In this state, (efficient) market prices play a key role in both allocating productive resources to maximize output, and ensuring optimal consumption choices which maximize consumer utility. If significant economic distortions are present appropriate shadow prices need to be used. The well known cost-benefit criterion accepts all projects whose net benefits are positive, i.e., aggregate benefits exceed costs (see Section 4). It is based on the weaker ‘quasi’ Pareto condition, which assumes that such net benefits could be redistributed from the potential gainers to the losers, so that no one is worse off than before. More generally, interpersonal comparisons of (monetized) welfare are fraught with difficulty – both within and across nations, and over time (e.g., the value of human life).

Economic sustainability

The pioneering work of Lindahl and Hicks (1946) laid the foundation for the modern concept underlying economic sustainability. It 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). Economic efficiency continues to play a key role. It is difficult to identify 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). Further problems arise in valuing these assets and the services they provide, particularly in the case of ecological and social resources (Munasinghe 1992). Uncertainty, irreversibility and catastrophic collapse are issues that pose additional difficulties, in determining sustainable development paths (Pearce and Turner 1990). Marginal analysis based on small perturbations (e.g., comparing incremental costs and benefits of economic activities) is commonly used in microeconomic approaches. Such methods are rather inappropriate for analysing large changes, discontinuous phenomena, and sudden transitions among multiple equilibria, because they assume smoothly changing variables. More recent work (especially at the cutting edge of the economics-ecology interface) has begun to explore the behaviour of large, non-linear, dynamic and chaotic systems, as well as newer concepts like system vulnerability and resilience.

2.3 Environmental Domain

The environmental dimension of development is a more recent concern, arising from the realization that human welfare ultimately depends on ecological services. It seeks to manage scarce natural resources in a prudent manner, reduce pollution, and protect biodiversity, because ignoring safe ecological limits will increase the risk of undermining long-run prospects for development. Dasgupta and Maler (1997) point out that until the 1990s, the mainstream development literature hardly mentioned the topic of environment (see for example, Stern 1989; Chenery and Srinivasan 1988, 1989; and Dreze and Sen
Examples of the growing literature on the theme of environment and sustainable development include books by Faucheux et al. (1996) describing models of sustainable development, and Munasinghe et al. (2001) explicitly addressing the links between growth and environment.

**Environmental sustainability**

Sustainability in the environmental sense highlights the overall viability and health of ecological systems – defined in terms of a comprehensive, multiscale, dynamic, hierarchical measure of resilience, vigour and organization (Costanza 2000). Holling (1973) provided the classic definition of resilience, based on the ability of an ecosystem to persist despite external shocks. Resilience is determined by the amount of change or disruption that will cause an ecosystem to switch from one system state to another (for further details, see Pimm 1991; Ludwig et al. 1997; and Petersen et al 1998). Vigour, which is associated with the primary productivity of an ecosystem, is analogous to output and growth as an indicator of dynamism in an economic system. Organization depends on both structure and complexity of an ecological or biological system. Higher states of organization imply lower levels of entropy. Thus, the second law of thermodynamics requires that the sustainability of more complex organisms depend on the use of low entropy energy derived from their environment, which is returned as (less useful) high entropy energy. The ultimate source of this energy is solar radiation.

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). Carrying capacities and safe thresholds are important concepts to avoid catastrophic ecosystem collapse (Holling 1986). Sustainability may be thought of in terms of the normal functioning and longevity of a nested hierarchy of ecological and socioeconomic systems, ordered according to scale – e.g., a human community would consist of many individuals, each of whom is composed of a large number of cells. ‘Panarchy’ is a term used to denote such a hierarchy of systems and their adaptive cycles across scales (Gunderson and Holling 2001). Any system is able to operate in its stable (sustainable) mode, because it is invigorated and energized by the faster cycles taking place in the sub-systems below it, while being simultaneously protected by the slower and more conservative changes in the super-system above it. In brief, both conservation and continuity from above, and innovation and change from below, are integral to the panarchy-based approach, helping to resolve the apparent paradox between the simultaneous need for both stability and change.

Maintaining the ecological *status quo* is not necessarily synonymous with sustainable development. From an economic perspective, a coupled ecological-socioeconomic system should evolve so as to maintain a level of biodiversity that will guarantee the resilience of the ecosystems on which human consumption and production depend. Compensation for the opportunities foregone by future generations is required by sustainable development, because today’s economic activity narrows the options available to unborn generations.
2.4 Social Domain

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

Equity and poverty alleviation are also important elements (see section below). Thus, protective strategies that reduce vulnerability, improve equity and ensure basic needs, are key aspects of social development. Future social development will require socio-political institutions that can adapt to meet the challenges of modernization -- which often destroy traditional coping mechanisms that have evolved in the past (especially to protect disadvantaged groups).

Social sustainability

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

Two important issues in this framework are equity and poverty. They have social, economic and environmental dimensions – see Figure 1(a). Recent worldwide statistics are compelling. 1.2 billion people barely survive on under US$1 per day (almost a quarter of the global population). The top 20 percentile of the world’s population consumes about 83 percent of total output, while the bottom 20 percentile consumes only 1.4 percent. Inequality is worsening – the per capita income ratio between the richest and the poorest 20 percentile groups, has risen from 30 to 1 in 1960, to over 80 to 1 by 1995. In poor countries, up to half the children under five years of age are malnourished, whereas the corresponding figure in rich countries is less than 5 percent.

Equity has primarily social, and some economic and environmental dimensions. It is an ethical and usually people-oriented concept, which focuses on the basic fairness of both the processes and outcomes of decision making. Societies normally seek to achieve equity by balancing and combining several criteria that help to assess the equity of any action. Such generic approaches include 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”.

Economic policies seeking to increase overall human welfare, rely on elements like poverty alleviation, improved income distribution and intra-generational (or spatial) equity (Sen 1981, 1984). There are shortcomings in utilitarianism, which underlies much of the economic approach to equity (Brown 1998). Broadly speaking, equity principles provide better tools for choosing (from a social perspective) among alternative patterns of consumption, whereas economic efficiency provides guidance on producing and consuming goods and services more efficiently.

Sustainability also depends on social equity, 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 empowering disadvantaged groups, as well as by enhancing pluralism and grass-roots participation in decision making (Rayner and Malone 1998). Key considerations in the long term include, inter-generational equity and safeguarding the rights of future generations. Meanwhile, the economic discount rate plays a key role with respect to both equity and efficiency aspects (Arrow et al. 1995).

Environmental equity has received more attention recently, because of the disproportionately greater environmental damages suffered by disadvantaged groups. At the same time, poverty alleviation efforts (which traditionally focused on raising monetary incomes), are being broadened to assist the poor -- who also face degraded environmental and social conditions.

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

The concept of fairness in the treatment of non-human forms of life or even inanimate nature, provides an even broader non-anthropocentric approach to equity. 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)).

2.6 Consistent integration of economic, social and environmental considerations

Let us compare the concepts of ecological, social and economic sustainability, before discussing integration. One useful approach stresses the maintenance of the set of opportunities, as opposed to the preservation of the value of the asset base (Githinji and Perrings 1992). Merely preserving a constant valued asset base is less meaningful, if preferences and technology vary through successive generations. The preservation of biodiversity enhances the size of the opportunity set and allows the system to retain resilience against external shocks, in the same manner that preservation of the capital stock protects economic assets for future consumption. However, there are differences. For example, using an ecological approach, loss of resilience (sustainability) implies a reduction in the self-organization of the system, but not necessarily a loss in productivity. By contrast, under the Hicks-Lindahl income measure, a society that consumes its fixed capital without replacement is not sustainable. For social systems, resilience depends to a certain extent on the capacity of human societies to adapt and continue functioning in the face of stresses and shocks. Thus, the similarities between the organization of human societies and ecological systems, and between biodiversity and cultural diversity, indicate parallelism between socio-cultural and ecological sustainability. The concept of co-evolution of social, economic and ecological systems within a larger, more complex adaptive system, provides useful longer term insights regarding the harmonious integration of the various elements of sustainable development – see Figure 1(a) (Munasinghe 1994; Costanza 1997).

A holistic and balanced sustainable development framework needs to integrate and reconcile the economic, social and environmental aspects. Because some of the most important decisions fall within the economic domain, economic analysis has a special role in contemporary national policy making. Until recently, many crucial environmental and social issues had been ignored in mainstream economics. Fortunately, 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).

The concepts of *optimality* and *durability* constitute two broad approaches for integrating the economic, social and environmental dimensions of sustainable development (see Box 2 for details). The main thrust is somewhat different in each case, although there are overlaps between the two approaches. The preferred approach is often determined by uncertainty. For example, subsistence farmers facing chaotic and unpredictable circumstances might opt for a more durable response that simply enhances their survival prospects, whereas relatively steady and well-ordered conditions may encourage macroeconomic planners to rely on optimizing models that attempts to control and even fine-tune outcomes.

### Box 2. Integrative Approaches

**Optimality**

The optimality-based approach has been widely used in economic analysis to generally maximize welfare (or utility), subject to the requirement that the stock of productive assets (or welfare itself) is non-decreasing in the long term. This assumption is common to most sustainable economic growth models – for useful reviews, see Pezzey (1992) and Islam (2001). The essence of the approach is illustrated by the simple example of maximization of the flow of aggregate welfare (W), cumulatively discounted over infinite time (t), as represented by the expression: \( \text{Max} \int_0^\infty W(C, Z) e^{-rt} \, dt \). Here, W is a function of C (the consumption rate), and Z (a set of other variables that influence welfare), while r is the discount rate. Further side constraints may be imposed to satisfy sustainability needs – e.g., non-decreasing stocks of productive assets (including natural resources).

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 (for more details about valuation, see Annex 2 below, and Munasinghe 1992 or Freeman 1993). More sophisticated economic optimization approaches seek to include environmental and social variables (e.g., by attempting to value environmental externalities, system resilience, etc). However, given the difficulties of quantifying and valuing many such ‘non-economic’ assets, the costs and benefits associated with market-based activities tend to dominate in most economic optimization models.

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

Side constraints are often necessary, because the underlying basis of economic valuation, optimization and efficient use of resources may not be easily applied to ecological objectives 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 (see Sections on cost-benefit and multi-criteria analysis, below). Moreover, the price system (which has time lags) might fail to anticipate reliably irreversible environmental and social harm, and non-linear system responses that could lead to catastrophic collapse. In such cases, non-economic indicators of environmental and social status would be helpful – e.g., area under forest cover, and incidence of conflict (see for example, Munasinghe and Shearer 1995; Hanna and Munasinghe 1995; UNDP 1998; World Bank 1998). The constraints on critical environmental and social indicators are proxies representing safe thresholds, which help to maintain the viability of those systems. In this context, techniques like multicriteria analysis may be required, to facilitate trade-offs among a variety of non-commensurable variables and objectives (see for example, Meier and Munasinghe 1994).

Risk and uncertainty will also necessitate the use of decision analysis tools [for a concise review of climate change decisionmaking frameworks, see Toth 1999). Recent work has underlined the social dimension of decision science, by pointing out that risk perceptions are subjective and depend on the risk measures used, as well as other factors such as ethno-cultural background, socio-economic status, and gender (Bennet 2000).

**Durability**

The second broad integrative approach would focus primarily on sustaining the quality of life – e.g., by satisfying environmental, social and economic sustainability requirements. Such a framework favours ‘durable’ development paths that permit growth, but are not necessarily economically optimal. There is more willingness to trade off some economic optimality for the sake of greater safety, in order to stay within critical environmental and social limits -- especially among increasingly risk-averse and vulnerable societies or individuals who face chaotic and unpredictable conditions (see the discussion on the precautionary principle in Section 3.1). The economic constraint might be framed in terms of maintaining consumption levels (defined broadly to include environmental services, leisure and other ‘non-economic’ benefits) – i.e., *per capita* consumption that never falls below some minimum level, or is non-declining. The environmental and social sustainability requirements may be expressed in terms of indicators of ‘state’ that seek to measure the durability or health (resilience, vigour and organization) of complex ecological and socio-economic systems. As an illustrative example, consider a simple durability index (D) for an ecosystem measured in terms of its expected lifespan (in a healthy state), as a fraction of the normal lifespan. We might specify: \( D = D(R,V,O,S) \); to indicate the dependence of durability on resilience (R), vigour (V), organization (O),...
Points of departure from the TAR

and the state of the external environment (S) – especially in relation to potentially
damaging shocks. There is the likelihood of further 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. For example, long-
standing social norms in many traditional societies have helped to protect the
environment (Colding and Folke 1997).

Durability encourages a holistic systemic viewpoint, which is important in
sustainomics analysis. The self-organizing and internal structure of ecological and
socioeconomic systems makes ‘the whole more durable (and valuable) than the sum of
the parts’. A narrow definition of efficiency based on marginal analysis of individual
components may be misleading (Schutz 1999). For example, it is more difficult to value
the integrated functional diversity in a forest ecosystem than the individual species of
trees and animals. Therefore, the former is more likely to fall victim to market failure (as
an externality). Furthermore, even where correct environmental shadow prices prevail,
some analysts point out that cost minimization could lead to homogenization and
consequent reductions in system diversity (Daly and Cobb 1989; Perrings et al. 1995).
Systems analysis also helps to identify the benefits of cooperative structures and
behaviour, which a more partial analysis may neglect. The possibility of many durable
paths favours simulation-based methods, including consideration of alternative world
views and futures (rather than one optimal result). This approach is consonant with recent
research on integrating human actors into ecological models (Ecological Economics
2000). Key elements include, multiple-agent modeling to account for heterogeneous
behaviour, recognition of bounded rationality leading to different perceptions and biases,
and more emphasis on social interactions which give rise to responses like imitation,
reciprocity and comparison.

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

2.7 Reconciling optimal and durable approaches

There is considerable scope to examine how both the optimality and durability
approaches might be applied side-by-side, in a consistent manner, to the various sub-
models within integrated assessment models or IAMs. In the case of climate change,
researchers are currently exploring the application of large and complex IAMs, which
contain coupled sub-models that represent a variety of ecological, geophysical and
socioeconomic systems – see next section, and (IPCC 1997). The determination of an
appropriate target trajectory for future global GHG emissions (and corresponding target
GHG concentration) also provides a simple but clear illustration of the interplay of the
durability and optimality approaches (for details see Example 1 below, and (IPCC 1996a; Munasinghe 1998a)).

National economic management provides another good example of how the two approaches complement one another. Typically, economywide policies involving both fiscal and monetary measures (e.g., taxes, subsidies, interest rates and foreign exchange rates) might be optimized on the basis of quantitative macroeconomic models. Nevertheless, decision makers inevitably modify these economically ‘optimal’ policies before implementing them, by taking into account other sociopolitical considerations based more on durability. These considerations include protection of the poor, regional factors, etc., which facilitate governance and stability.

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

3. NEXUS OF CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT

3.1 Circular relationship between climate change and sustainable development

The full cycle of cause and effect between climate change and sustainable development is summarised in Figure 2, which outlines an integrated assessment modelling (IAM) framework (IPCC 2001a).

Each socio-economic development path (driven by the forces of population, economy, technology, and governance) gives rise to different levels of greenhouse gas emissions. These emissions accumulate in the atmosphere, increasing the greenhouse gas concentrations and disturbing the natural balance between incident solar radiation and energy re-radiated from the earth. Such changes give rise to the enhanced greenhouse effect that increases radiative forcing of the climate system. The resultant changes in climate will persist well into the future, and impose stresses on the human and natural systems. Such impacts will ultimately have effects on socio-economic development paths, thus completing the cycle. The development paths also have direct effects on the
natural systems, in the form of non-climate stresses such as changes in land use leading to deforestation and land degradation.

Figure 2. Integrated Assessment Modelling (IAM) Framework for Analysing Climate Change and Sustainable Development linkages

To summarise, the climate and sustainable development domains interact in a dynamic cycle, characterised by significant time delays. Both impacts and emissions, for example, are linked in complex ways to underlying socio-economic and technological development paths. Adaptation reduces the impact of climate stresses on human and natural systems, while mitigation lowers potential greenhouse gas emissions. Development paths strongly affect the capacity to both adapt to and mitigate climate change in any region. In this way adaptation and mitigation strategies are dynamically connected with changes in the climate system and the prospects for ecosystem adaptation, food production, and long-term economic development.

Thus climate change impacts are part of the larger question of how complex social, economic, and environmental sub-systems interact and shape prospects for sustainable development. There are multiple links. Economic development affects ecosystem balance and, in turn, is affected by the state of the ecosystem. Poverty can be both a result and a cause of environmental degradation. Material- and energy-intensive life styles and
continued high levels of consumption supported by non-renewable resources, as well as rapid population growth are not likely to be consistent with sustainable development paths. Similarly, extreme socio-economic inequality within communities and between nations may undermine the social cohesion that would promote sustainability and make policy responses more effective. At the same time, socio-economic and technology policy decisions made for non-climate-related reasons have significant implications for climate policy and climate change impacts, as well as for other environmental issues. In addition, critical impact thresholds, and vulnerability to climate change impacts, are directly connected to environmental, social and economic conditions, and institutional capacity.

3.2 Economic, social and environmental risks arising from climate change

First, global warming poses a significant potential threat to the future economic well-being of large numbers of human beings. In its simplest form, the economic efficiency viewpoint will seek to maximize the net benefits (or outputs of goods and services) from the use of the global resource represented by the atmosphere. Broadly speaking, this implies that the stock of atmospheric assets, which provide a sink function for GHGs needs to be maintained at an optimum level. As indicated in Example 1 below, this target level is defined at the point where the marginal GHG abatement costs are equal to the marginal avoided damages. The underlying principles are based on optimality and the economically efficient use of a scarce resource, i.e., the global atmosphere.

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

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

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

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

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

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

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

### 3.3 Vulnerability, resilience, adaptation and adaptive capacity

As discussed earlier, durability criteria or constraints focus on maintaining the quality and quantity dimensions of asset stocks. In the area of climate change, the various forms of capital are viewed as a bulwark that decreases vulnerability to external shocks and reduces irreversible harm, rather than mere accumulations of assets that produce economic outputs. System resilience, vigour, organisation and ability to adapt will depend dynamically on the capital endowment, as well as on the magnitude and rate of change of a shock.

It is useful at this stage to define certain terms more precisely, in the context of climate change (IPCC 2001a). **Vulnerability** is the extent to which human and natural systems are...
susceptible to, or unable to cope with the adverse effects of climate change. It is a function of the character, magnitude and rate of climate variation, as well as the sensitivity and adaptive capacity of the system concerned. Resilience is the degree of change a system can undergo, without changing state. Adaptation refers to the adjustments in human and natural systems, in response to climate change stresses and their effects, which moderate damage and exploit opportunities for benefit (e.g., building higher sea walls, or developing drought- and salt-resistant crops). Different types of adaptation include anticipatory versus reactive adaptation, private versus public adaptation, and autonomous versus planned adaptation. Adaptive capacity is the ability of a system to adjust to climate change.

Strengthening adaptive capacity is a key policy option, especially in the case of the most vulnerable and disadvantaged groups. Adaptive capacity itself will depend on the availability and distribution of economic, natural, social, and human resources; institutional structure and access to decision making processes; information, public awareness and perceptions; menu of technology and policy options; ability to spread risk; etc. (Smit et al. 2001; Yohe and Tol 2001). In turn, performance across these variables is likely to be linked to patterns of economic and social development in a given country or specific location.

3.4 Mitigation and mitigative capacity

The IPCC recently elaborated six different reference scenarios that show a wide variety of alternative development pathways over the next century, each yielding a very different pattern of GHG emissions (IPCC 2000). Lower emission scenarios require less carbon-intensive energy resource development than in the past. In the past decade, progress on GHG emission reduction technologies has been faster than anticipated. Improved methods of land use (especially forests) offer significant potential for carbon sequestration. Although not necessarily permanent, such methods might allow time for more effective mitigation techniques to be developed. Ultimately, mitigation options will be determined by differences in the distribution of natural, technological, and financial resources, as well as mitigation costs across nations and generations (IPCC 2001a).

Although the path to a low emission future will vary by country, the IPCC results indicate that appropriate socio-economic changes combined with known mitigation technology and policy options could help to achieve a range of atmospheric CO2 stabilisation levels around 550 ppmv or less, in the next 100 years. Social learning and innovation, and changes in institutional structure could play an especially important role. Policy options that yield no-regrets outcomes will help to reduce GHG emissions at no or negative social cost. However, the incremental costs of stabilising atmospheric CO2 concentrations over the next century rise sharply as the target concentration level falls from 750 ppmv to 450 ppmv.

Integrating climate policies with non-climate national sustainable development strategy will increase the effectiveness of mitigation efforts. However, there are many technical, social, behavioural, cultural, political, economic, and institutional barriers to implementing mitigation options within countries. Coordinating actions across countries
and sectors could reduce mitigations costs, and limit concerns about competitiveness, conflicts over international trade regulations, and carbon leakage. To summarize, early actions including mitigation measures, technology development, and better scientific knowledge about climate change, will increase the possibilities for stabilising atmospheric GHG concentrations.

The effectiveness of future mitigation could be improved by strengthening *mitigative capacity* (i.e., the social, political and economic structures and conditions required for mitigation). The mitigative capacity among nations is inevitably varied and suggests that more research and analytic capacity is needed in developing countries. Increases in mitigative capacity could allow climate change considerations to be more effectively integrated with action to address other (non-climate) sustainable development challenges in a manner that effectively limits GHG emissions over time, while maximising the developmental co-benefits of mitigative actions. Such a ‘win-win’ approach is examined below.

### 3.5 Tunneling to restructure growth more sustainably

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

The above approach is illustrated in Figure 3, which shows how a country’s GHG emissions might vary with its level of development. One would expect carbon emissions to rise more rapidly during the early stages of development (along AB), and begin to level off only when *per capita* incomes are higher (along BC). A typical developing country would be at a point such as B on the curve, and an industrialized nation might be at C. The key point is that if the developing countries were to follow the growth path of the industrialized world, then atmospheric concentrations of GHGs would soon rise to dangerous levels. The risk of exceeding the safe limit (shaded area) could be avoided by adopting sustainable development strategies that would permit developing countries to progress along a path such as BD (and eventually DE), while also reducing GHG emissions in industrialized countries along CE.

As outlined earlier, growth inducing economywide policies could combine with imperfections in the economy to cause environmental harm. Rather than halting economic growth, complementary policies may be used to remove such imperfections and thereby protect the environment. It would be fruitful to encourage a more proactive approach whereby the developing countries could learn from the past experiences of the industrialized world – by adopting sustainable development strategies and climate change measures which would enable them to follow development paths such as BDE, as shown
in the Figure (Munasinghe 1998b). Thus, the emphasis is on identifying policies that will help de-link carbon emissions and growth, with the curve in Figure 3 serving mainly as a useful metaphor or organizing framework for policy analysis.

**Figure 3** Environmental risk versus development level

![Graph showing Environmental risk versus Development level](source)

*Source:* adapted from Munasinghe (1995)

This representation also illustrates the complementarity of the optimal and durable approaches discussed earlier. It has been shown that the higher path ABC in the Figure could be caused by economic imperfections which make private decisions deviate from socially optimal ones (Munasinghe 1998c). Thus the adoption of corrective policies would reduce such divergences from optimality and reduce GHG emissions per unit of output, thereby facilitating movement along the lower path ABD. Concurrently, the durability viewpoint suggests that flattening the peak of environmental damage (at C) would be especially desirable to avoid exceeding the safe limit or threshold representing dangerous accumulations of GHGs (shaded area in Figure 3).

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

\[ G = \frac{Q}{P} \times \frac{Y}{Q} \times \frac{G}{Y} \times P; \]

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

### 3.6 Relevant principles for policy formulation

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

An important social principle is that climate change should not be allowed to worsen existing inequities – although climate change policy cannot be expected to address all prevailing equity issues. Some special aspects include:
• the establishment of an equitable and participative global framework for making and implementing collective decisions about climate change;
• reducing the potential for social disruption and conflicts arising from climate change impacts; and
• protection of threatened cultures and preservation of cultural diversity.

While economic theory is best suited to designing efficient economic policies, ethical and social considerations are helpful in addressing equity issues (Pinguelli-Rosa and Munasinghe 2002). From the social equity viewpoint, the polluter pays principle (mentioned above) is based not only on economic efficiency, but also on fairness. An extension of this idea is the principle of recompensing victims – ideally by using the revenues collected from polluters. There is also the moral/equity issue concerning the extent of the polluters’ obligation to compensate for past emissions (i.e., a form of environmental debt). As mentioned earlier, weighting the benefits and costs of climate change impacts according to the income levels of those who are affected, has also been suggested as one way of redressing inequitable outcomes. Kverndokk (1995) argued that conventional justice principles would favour the equitable allocation of future GHG emission rights on the basis of population. Equal per capita GHG emission rights (i.e., equal access to the global atmosphere) is consistent also with the UN human rights declaration underlining the equality of all human beings.

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

Several other 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 1993).
4. TOOLS FOR ANALYSIS AND ASSESSMENT

Some important tools and policy principles that may be used for analysis and assessment are summarised below. More details are provided in Annex 2.

4.1 Action impact matrix (AIM)

The Action Impact Matrix (AIM) is a tool to facilitate the sustainability of development by analysing economic, environmental and social interactions of various development policies. Global environmental problems, such as climate change, should be a key aspect of the assessment. For example, macroeconomic policies adopted routinely by national policy makers often have significant environmental and social impacts (Munasinghe 2002). In particular, such policies shape the development paths of nations, which in turn affect not only the severity of future climate change impacts, but also vulnerability to climate change, as well as adaptive and mitigative capacities.

The AIM approach will help to find ‘win-win’ policies and projects, which not only achieve conventional macroeconomic objectives (like growth), but also make local and national development efforts more sustainable. With respect to climate change, the approach can identify key linkages between development efforts and climate change issues like vulnerability, impacts (including changes in GHG emission levels), mitigation and adaptation. It would help to identify development paths that embed national climate change policies in the overall sustainable development strategy.

The process of preparing the matrix encourages stakeholder participation in identifying priority issues and relevant data, posing the appropriate questions, interpreting the results, and formulating and implementing policy outcomes. In particular, it facilitates consensus building among the development, climate change, and environmental communities.

The AIM itself promotes an integrated view, meshing development decisions with priority economic, environmental and social impacts. Usually, the rows of the table list the main development interventions (both policies and projects), while the columns indicate key sustainable development issues and impacts (including climate change vulnerability). Thus the elements or cells in the matrix help to:

- identify explicitly the key issues and linkages;
- focus the analysis on the most important vulnerabilities and issues; and
- suggest action priorities and remedies.

At the same time, the organisation of the overall matrix facilitates the tracing of impacts via complex pathways, as well as the coherent articulation of the links among a range of development actions - both policies and projects. More details are provided in Example 2.
4.2 Indicators

It will be important to monitor if and how climate change or climate change policies may affect stocks of natural, social and economic capital in different regions of the world. The risks to natural and economic capital are well documented in the recent IPCC Third Assessment Report (IPCC 2001a - Ch.19 of WGII; IPCC 2001b - Section 3), whereas the social dimension is more difficult to measure and has only received attention in the past few years. For example, recent OECD work advances definitions of human capital to encompass human well-being -- measured through education and health indicators and social capital as networks of shared norms, values and understanding that facilitates cooperation within and between groups (OECD 2001). However these concepts of social capital have not yet been systematically applied in the assessment of climate change impacts or of climate policies. Nevertheless, these different types of stocks of assets are central to the optimality and durability approaches, as well as to the capacity to adapt to and mitigate climate change, and multi-dimensional indicators could be useful in assessing policy options. Annex 2 (Section A2.1) summarises the literature which describe a wide variety of indicators that are already in use. It may be possible to adapt some of these for use in the assessment of connections between development and climate policies.

4.3 Cost-Benefit Analysis (CBA)

Cost-benefit analysis (CBA) is one well-known example of a single value approach, which seeks to assign economic values to the various consequences of an economic activity. The resulting costs and benefits are combined into a single decision making criterion like the net present value (NPV), internal rate of return (IRR), or benefit-cost ratio (BCR). Useful variants include cost effectiveness, and least cost based methods. Both benefits and costs are defined as the difference between what would occur with and without the project being implemented. The economic efficiency viewpoint usually requires that shadow prices (or opportunity costs) be used to measure costs and benefits. All significant impacts and externalities need to be valued as economic benefits and costs. However, since many environmental and social effects may not be easy to value in monetary terms, CBA is used in practice mainly as a tool to assess economic and financial outcomes. Annex 2 (Section A2.2) provides further details.

4.4 Multi-Criteria Analysis (MCA)

Multi-criteria analysis (MCA) or multi-objective decision-making is particularly useful in situations when a single criterion approach like CBA falls short – especially where significant environmental and social impacts cannot be assigned monetary values (see Annex 2, Section A2.3). In MCA, desirable objectives are specified and corresponding attributes or indicators are identified. Unlike in CBA, the actual measurement of indicators does not have to be in monetary terms – i.e., different environmental and social indicators may be developed, side by side with economic costs and benefits. Thus, more explicit recognition is given to the fact that a variety of both monetary and non-monetary objectives and indicators may influence policy decisions. MCA provides techniques for comparing and ranking different outcomes, even though a variety of indicators are used.
4.5 Sustainable Development Assessment (SDA)

Sustainable development assessment (SDA) is an important tool to ensure balanced analysis of both development and sustainability concerns. The ‘economic’ component of SDA is based on conventional economic and financial analysis (including cost benefit analysis, as described earlier). The other two key components are environmental and social assessment (EA and SA) – e.g., see World Bank 1998. Poverty assessment is often interwoven with SDA. Economic, environmental and social analyses need to be integrated and harmonised within SDA. Since traditional decision making relies heavily on economics, a first step towards such an integration would be the systematic incorporation of environmental and social concerns into the economic policy framework of human society (see Annex 2, Section A2.4).

5. EXAMPLES ANALYSING THE LINKAGES BETWEEN SUSTAINABLE DEVELOPMENT CLIMATE CHANGE

The concepts outlined above are highlighted in practical examples outlined below. These case studies provide additional insights into the potential convergence between optimality and durability approaches, and the practical use of the various analytical tools to make development MORE sustainable at the global-transnational, national, sub-national and local-project scales.

5.1 Global-transnational scale: climate change policy objectives

The climate change problem fits in quite readily within the broad conceptual framework of sustainomics, described above. For a variety of reasons described in the previous section, decision makers are beginning to show more interest in the assessment of how serious a threat climate change poses to the future basis for improving human welfare (Munasinghe 2000; Munasinghe and Swart 2000). Typically, increased GHG emissions and other unsustainable practices are likely to undermine the security of nations and communities, through economic, social and environmental impoverishment, as well as inequitable distribution of adverse impacts – with undesirable consequences such as large numbers of ‘environmental’ refugees (Lonergan 1993; Ruitenbeek 1996; Westing 1992).

Thus, human-induced climate change is a global environmental problem that will have impacts at the local, regional and (potentially) global levels. Successfully limiting the pace and extent of the harmful effects of climate change will require international co-operation. The first example examines the interplay of impacts, adaptation, and mitigation, with optimality and durability based approaches in determining global GHG emission levels (Munasinghe 2001). GHG concentrations should “be stabilised at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner” (Article 2, UNFCCC 1993).
**Example 1: Setting global objectives for climate change co-operation**

Under an economic optimising framework, the ideal solution would be to estimate two curves associated with different GHG emission profiles:

a) the marginal avoided damages (MAD) which depends on climate change impacts and adaptation costs; and

b) the long-run marginal abatement costs (MAC) based on mitigation efforts.

The MAD and MAC curves are shown in Figure 4(c), where the error bands on the curves indicate measurement uncertainties (IPCC 1996a).

Figure 4. Determining Global Abatement Targets based on different approaches: A) absolute standard; B) affordable standard; C) cost-benefit optimum

Source: Adapted from IPCC 1996a
The optimisation approach indicates that the desirable emission level would be determined at the point where future benefits (in terms of climate change damage avoided by reducing one unit of GHG emissions) are just equal to the corresponding costs (of mitigation measures required to reduce that unit of GHG emissions), i.e., $\text{MAD} = \text{MAC}$ at point ROP.

"Durable" strategies become more relevant when we recognise that MAC and/or MAD might be poorly quantified and uncertain. Figure 4(b) assumes that MAC is better defined than MAD. Here, 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 socio-economic disruption. This line of reasoning takes into consideration the capability of social and economic systems to absorb the shock of the financial burden of mitigation, and is closer to the durability approach.

Finally, Figure 4(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 (at $R_{AS}$) or safe limit, which would avoid an unacceptably high risk of impact damage to ecological (and/or social) systems. This last approach places greater emphasis on vulnerability, impacts and adaptation, and would be more in line with the durability concept.

5.2 National-economy-wide scale: macroeconomic management

At the project level, conventional economic valuation of environmental impacts is a key step in incorporating the results of environmental assessment into economic decision making – e.g., cost-benefit analysis (see also Annex 2, Section A2.4). Meanwhile, 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. These efforts have yielded useful new indicators and measures of national product and wealth, including natural resource (stock) accounts, resource and pollutant flow accounts, environmental expenditure accounts, and alternative national accounts aggregates (Atkinson et al. 1997). An important umbrella framework is the United Nations Integrated System of Environmental and Economic Accounting (SEEA), which is the first step towards standardizing the various accounting approaches (UN Statistical Office 1993). The SEEA is designed to be a satellite account to the conventional System of National Accounts (SNA), i.e., it is an adjunct to rather than a modification of the core accounts. It is highly complex, involving disaggregation of the standard accounts to highlight environmental relationships, linked physical and monetary accounting, imputations of environmental costs, and extensions of the production boundary of the SNA. A comprehensive framework like the SEEA may be used to estimate various national accounts aggregates such as ‘green GNP’ and ‘genuine savings’ – which are usually adjusted downward to reflect the costs of net resource depletion and environmental pollution (Munasinghe 2002).

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

Clearly, sustainable development strategies (including options that reduce vulnerability and strengthen adaptive and mitigative capacities), need to be made more consistent with other national development policies. Such strategies are more likely to be effective than isolated technological or policy options. In particular, the highest priority needs to be given to finding any ‘win-win policies’, which not only achieve conventional macroeconomic objectives, but also make local and national development efforts more sustainable, and address climate change issues. Such policies could help to build support for sustainable climate change strategies among the traditional decision making community, and conversely make climate specialists more sensitive to shorter term macroeconomic and development goals. 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.

**Scope of policies and range of impacts**

The most important economic management tools currently in common use are economy-wide reforms, which include structural adjustment packages. Economy-wide (or country-wide) policies consist of both sectoral and macroeconomic policies that 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 sector-wide 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 economy-wide policies and sustainable development, we briefly examine several examples that provide a flavour of the possibilities involved (for details, see Munasinghe 1996; Jepma and Munasinghe 1998).

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 pollution emitted (i.e., so called ‘win-win’ outcomes). For example, improving property rights and strengthening incentives for better land management not only yield economic gains and reduce deforestation of open access lands (e.g., due to ‘slash and burn’ agriculture), but also help to reduce vulnerability, improve the adaptive capacity of ecosystems, and mitigate greenhouse gas emissions.
At the same time, growth-inducing economy-wide policies could lead to increased environmental damages and greater vulnerability to climate change, unless the macro-reforms are complemented by additional environmental and social measures. Such negative impacts are invariably unintended and occur when some broad policy changes are undertaken while other hidden or neglected economic and institutional imperfections persist (Munasinghe and Cruz 1994). In general, the remedy does not require reversal of the original reforms, but rather the implementation of additional complementary measures (both economic and non-economic) that reduce climate change vulnerability and increase adaptive and mitigative capacities. For example, export promotion measures and currency devaluation might increase the profitability of timber exports (see the example below). This in turn, could further accelerate deforestation that was already under way due to low stumpage fees and open access to forest lands. Establishing property rights and increasing timber charges would reduce deforestation, thereby diminishing vulnerability to climate change and improving both adaptation and mitigation prospects, without interrupting the macroeconomic benefits of trade liberalisation.

Similarly, market-oriented liberalisation in a country could lead to economic expansion and the growth of wasteful resource-intensive activities in certain sectors – if such growth was associated with subsidised resource prices. Such a situation is reported in a case study of Morocco, where irrigation water is the scarce resource affected by economic expansion (Munasinghe 1996). Eliminating the relevant resource price subsidy could help to reduce local water scarcities and reduce vulnerability to future climate change, while enhancing macroeconomic gains. Other countrywide policies could influence adaptation to climate change, negatively or positively. For example, national policies that encouraged population movement into low-lying coastal areas might increase their vulnerability to future impacts of sea level rise. On the other hand, government actions to protect citizens from natural disasters – such as investing in safer physical infrastructure or strengthening the social resilience of poorer communities – could reduce vulnerability to extreme weather events associated with future climate change (Clarke and Munasinghe 1995).

In this context, systematic assessment of economic-environmental-social interactions helps to formulate effective sustainable development policies, by linking and articulating these activities explicitly. In particular, it is important to identify those systems, sectors and communities that are likely to be the most vulnerable to climate change, especially if they are already under threat due to existing national policies. Implementation of such an approach would be facilitated by constructing a simple Action Impact Matrix or AIM, as described below in Example 2 (Munasinghe and Cruz 1994).

**Example 2: Action impact matrix (AIM) for policy analysis**

A simple example of the Action Impact Matrix (AIM) – is shown in Table 1, although an actual AIM would be very much larger and more detailed (Munasinghe 1992, 1996). The far left column of the Table lists examples of the main development interventions (both policies and projects), while the top row indicates some typical sustainable development issues -- including climate change vulnerability and adaptive and mitigative capacity.
Table 1. A simplified preliminary Action Impact Matrix (AIM).  

<table>
<thead>
<tr>
<th>Activity/Policy</th>
<th>Impacts On Key Sustainable Development Issues</th>
<th>Land Degradation &amp; Biodiversity Loss</th>
<th>Water Scarcity &amp; Pollution</th>
<th>Resettlement &amp; Social Effects</th>
<th>Climate Change Effects (eg, vulnerability, impacts and adaptation; and mitigation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroeconomic &amp; Sectoral Policies</td>
<td>Macroeconomic and sectoral improvements</td>
<td>Positive impacts due to removal of distortions</td>
<td>Negative impacts mainly due to remaining constraints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exchange Rate (1)</td>
<td>Improve trade balance and economic growth</td>
<td>(-H) (deforest open-access areas)</td>
<td>(-H)</td>
<td></td>
<td>(-M) (more vulnerable, less adaptive &amp; mitigative capacity)</td>
</tr>
<tr>
<td>Water Pricing (2)</td>
<td>More efficient water use and economic efficiency</td>
<td>(+M) (water use efficiency)</td>
<td>(+M)</td>
<td></td>
<td>(+M) (less vulnerable, better adaptive capacity)</td>
</tr>
<tr>
<td>Others (3)</td>
<td>Complementary Measures and Remedies*</td>
<td>Specific socio-economic and environmental gains</td>
<td>Enhance positive impacts and mitigate negative impacts (above) of broader macroeconomic and sectoral policies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Based (4)</td>
<td>Improve effectiveness of investments</td>
<td>(+M) (pollution tax)</td>
<td>(+L) (less vulnerable)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Market Based (5)</td>
<td>(+H) (property rights)</td>
<td>(+M) (public sector accountability)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment Projects</td>
<td>Improve effectiveness of investments</td>
<td>Investment decisions made more consistent with broader policy and institutional framework</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project 1 (Hydro Dam) (6)</td>
<td></td>
<td>(-H) (inundate forests)</td>
<td>(-M) (displace people)</td>
<td>(+M, -L) (less fossil fuel use, more vulnerable)</td>
<td></td>
</tr>
<tr>
<td>Project 2 (Re-afforest and relocate) (7)</td>
<td></td>
<td>(+H) (replant forests)</td>
<td>(+M) (relocate people)</td>
<td>(+M) (absorb carbon, less vulnerable)</td>
<td></td>
</tr>
<tr>
<td>Other Projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: adapted from Munasinghe and Cruz (1994)

Notes:

1. A few examples of typical policies and projects as well as illustrative impact assessments are indicated. + and - signify beneficial and harmful impacts, while H and M indicate high and moderate intensity. The AIM process helps to focus on the highest priority economic social and environmental issues.

2. Commonly used market-based measures include effluent charges, tradable emission permits, emission taxes or subsidies, bubbles and offsets (emission banking), stumpage fees, royalties, user fees, deposit-refund schemes, performance bonds, and taxes on products (such as fuel taxes). Non-market based measures comprise regulations and laws specifying environmental standard (such as ambient standards, emission standards, and technology standards) which permit or limit certain actions (‘dos’ and ‘don’ts’).
As indicated earlier, the elements or cells in the matrix help to explicitly identify the key issues and linkages, focus the analysis on the most important vulnerabilities and adaptation issues, and suggest action priorities and remedies. At the same time, the organisation of the overall matrix facilitates the tracing of impacts, as well as the coherent articulation of the links among development policies and projects.

Table 2. Typical Elements from a Vulnerabilities Table

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>BIO-PHYSICAL IMPACTS</th>
<th>SOCIO-ECONOMIC IMPACTS</th>
<th>CAUSES AND DRIVERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforestation and Biodiversity Loss</td>
<td>Area under forest cover, threatened species, etc.</td>
<td>Stakeholder income levels, livelihoods at risk, value of forest loss, etc.</td>
<td>Landless population, open access to forests, lack of stumpage fees, etc.</td>
</tr>
</tbody>
</table>

The next task would be the preparation of a ‘development activities table’ (Table 3). The first column of this table would contain major development goals and policies, such as an exchange rate devaluation (to improve the balance of payments). The second column might indicate the current status from a development perspective – in the forest sector, typical effects might include balance of payments improvement due to greater timber exports, increased timber demand for exports and local construction, higher deforestation rate, illegal felling, and ‘slash and burn’ agriculture. The third column could contain environmental and climate related implications, such as threats to the adaptive capacity of forest areas, soil erosion, and loss of watersheds. The fourth column would set out ongoing or proposed remedies, including restricted access to forests, better enforcement, higher stumpage fees, and re-afforestation. A normal development activities table would summarise information on many such major policy areas, dealing with acceleration of economic growth, import substitution, fiscal and monetary balance, industrialisation, agricultural self-sufficiency, energy development, etc.

Table 3. Typical Elements from a Development Activities Table

<table>
<thead>
<tr>
<th>DEVELOPMENT GOALS AND POLICIES</th>
<th>DEVELOPMENT IMPACTS</th>
<th>ENVIRONMENT AND CLIMATE IMPACTS</th>
<th>REMEDIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchange rate devaluation to improve balance of payments</td>
<td>Forest Sector</td>
<td>Adaptive capacity of forests, watershed loss, soil erosion, etc.</td>
<td>Restrict forest access, better enforcement, higher stumpage fees, more re-afforestation, etc.</td>
</tr>
<tr>
<td></td>
<td>Higher timber demand for exports and local construction, increased deforestation, illegal timber felling, ‘slash and burn’ agriculture, etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The AIM would be put together by bringing all stakeholders together, to integrate the information in the two tables prepared earlier. Table 3 shows how a simple AIM might be organised, by combining information on development activities and vulnerabilities.
Screening and problem identification

One of the early objectives of the AIM-based process is to help in screening and problem identification – by preparing a preliminary matrix that identifies broad relationships, and provides a qualitative idea of the magnitudes of the impacts. Thus, the preliminary AIM would be used to prioritise the most important links between policies and their sustainability impacts (especially climate effects). As mentioned earlier, row (1) of Table 3 shows how a currency devaluation aimed at improving the trade balance, may make timber exports more profitable and lead to deforestation of open access forests. Column (A) indicates a negative local environmental side effect involving severe land degradation and biodiversity loss. In the same row, column (D) shows negative climate change effects, including greater vulnerability etc. Some air pollution and GHG emissions due to burning of wood might also occur, although this is not indicated here. Potential remedial policies are shown lower down in column (A) – e.g., complementary measures to strengthen property rights and restrict access to forest areas, which would prevent the deforestation. As shown in column (D), such steps would reverse the negative climate change effects.

A second example shown in row (2) involves raising (subsidised) water prices to reflect marginal supply costs -- to improve the efficiency of water use, and thereby have the additional positive effect of decreasing water scarcity [column (B)] and reducing vulnerability to future climate change [column (D)]. A complementary measure indicated in row (4), column (B) consists of adding water pollution taxes to water supply costs, which will help to reduce both water pollution and damage to human and ecological health, while reducing vulnerability to climate change. As shown in row (5), column (B), improving competition and public sector accountability will reinforce favourable responses to these price incentives, by reducing the ability of inefficient firms to pass on the increased costs of water to consumers or to transfer their losses to the government.

The third example involves a major hydroelectric project, shown in row (6), which has two adverse impacts (inundation of forested areas and village dwellings), as well as one net positive impact (the replacement of thermal power generation, which would reduce air pollution and GHG emissions – despite potential methane emissions from inundated vegetation). A re-afforestation project coupled with resettlement schemes, as indicated in row (7), would help to address the negative impacts.

This matrix-based approach therefore encourages the systematic articulation and co-ordination of policies and projects to make development more sustainable. Based on readily available data, it would be possible to develop such an initial matrix as the organising framework for case studies in the OECD project.

Analysis and remediation

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

The types of more detailed analyses, which could be applied to the high priority matrix elements in the AIM, would be case specific and depend on planning goals, available data and resources. They may range from the application of conventional sectoral economic analysis methods (appropriately modified in scope to incorporate environmental impacts), to fairly comprehensive system or multisector modelling efforts – including computable general equilibrium (CGE) models that include both conventional economic, as well as environmental or resource variables. Sectoral and partial equilibrium analyses are more useful to trace details of direct impacts, whereas CGE modeling provides a more comprehensive but aggregate view, and insights into indirect linkages (Munasinghe 1996, 2002). Often, such models are built around an expanded input-output (I-O) table or social accounting matrix (SAM), which includes information based on an integrated system of environmental and economic accounts (SEEA – discussed earlier). The expanded I-O, SAM and SEEA framework helps to incorporate environmental and social considerations into sectoral and macroeconomic analysis. As a typical example Figure 5 summarises the flow of the analytical process linking broad national-level development plans and models, to detailed climate change vulnerabilities, impacts, adaptation, and mitigation at the local level.

**Figure 5.** Assessing the linkages between national development plans and climate policy (adaptation and mitigation) using the Action Impact Matrix (AIM)

*Source: OECD (2002).*
5.3 Sub-national scale: energy sector planning and policy analysis

At the sub-national scale, sustainable development issues arise in various forms. In this section, we consider an example dealing with issues in the important energy sector of the Sri Lankan economy.

Example 3: Improving energy sector decision-making in Sri Lanka

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

Sustainable energy development framework

A framework for sustainable energy decision making is depicted in Figure 6. The middle column of the Figure shows the core of the framework comprising an integrated multilevel analysis that can accommodate issues ranging from the global scale down to the local or project level. At the top level, individual countries constitute elements of an international matrix. Economic and environmental conditions imposed at this global level constitute exogenous inputs or constraints on national level decision-makers. Typical examples of such external constraints include emerging agreements under the UNFCCC, which have implications for both adaptation and mitigation.

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

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

Figure 6  Framework for sustainable energy development

![Framework for sustainable energy development](image)

Source: adapted from Munasinghe (1990)

Methodology

The incorporation of environmental and social externalities into decision making is particularly important in the electric power sector (see also Annex 2, Section A2.4). It is also clear that in order for environmental and social concerns to play a real role in power sector decision making, one must address these issues early -- at the sectoral and regional planning stages, rather than later at the stage of environmental and social assessment of individual projects. Many of the valuation techniques discussed earlier are most appropriate at the micro-level, and may therefore be very difficult to apply in situations involving choices among a potentially large number of technology, site, and mitigation options. Therefore, multi-criteria analysis (MCA) may be applied, since it allows for the appraisal of alternatives with differing objectives and varied costs and benefits, which are often assessed in differing units of measurement.

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

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

Main results of Example 3

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

Great care needs to be exercised in selecting a limited number of key criteria or attributes, which normally reflect issues of national as well as local project level significance, and have implications for both adaptation and mitigation policies. To capture the potential impact on global warming, CO₂ emissions were defined as the appropriate proxy. Three key indicators based on impacts on human beings, social systems, and ecological systems, were identified. Human health impacts were measured through population-weighted increments in both fine particulates and NOₓ attributable to each source. As an illustrative social impact, employment creation was used. To capture the potential biodiversity impacts, a composite biodiversity loss index was derived (Table 4).
Table 4. Deriving a preliminary biodiversity index

<table>
<thead>
<tr>
<th>Rank</th>
<th>Ecosystem</th>
<th>Relative biodiversity value (w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lowland wet evergreen forest</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>Lowland moist evergreen forest</td>
<td>0.98</td>
</tr>
<tr>
<td>3</td>
<td>Lower montane forest</td>
<td>0.90</td>
</tr>
<tr>
<td>4</td>
<td>Upper montane forest</td>
<td>0.90</td>
</tr>
<tr>
<td>5</td>
<td>Riverrine forest</td>
<td>0.75</td>
</tr>
<tr>
<td>6</td>
<td>Dry mixed evergreen forest</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>Villus</td>
<td>0.4</td>
</tr>
<tr>
<td>8</td>
<td>Mangroves</td>
<td>0.4</td>
</tr>
<tr>
<td>9</td>
<td>Thorn forest</td>
<td>0.3</td>
</tr>
<tr>
<td>10</td>
<td>Grasslands</td>
<td>0.3</td>
</tr>
<tr>
<td>11</td>
<td>Rubber lands</td>
<td>0.2</td>
</tr>
<tr>
<td>12</td>
<td>Home gardens</td>
<td>0.2</td>
</tr>
<tr>
<td>13</td>
<td>Salt marshes</td>
<td>0.1</td>
</tr>
<tr>
<td>14</td>
<td>Sand dunes</td>
<td>0.1</td>
</tr>
<tr>
<td>15</td>
<td>Coconut lands</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Source: adapted from Meier and Munasinghe (1994)*

We define $G_i$ as the average biodiversity loss index value per unit of energy produced per year at hydro site $i$.

$$G_i = \sum_j (w_j)(A_{ij})/ [\text{Hydroelectric energy generated per year at site } i]$$

where $A_{ij}$ is the area of ecosystem type $j$ at hydro site $i$, and $w_j$ is relative biodiversity value of ecosystem type $j$ (as defined in Table 4).

Figure 7(a) illustrates a typical trade-off curve for biodiversity loss (see also, the earlier discussion on MCA in Annex 2, Section 1.3). The "best" solutions lie closest to the origin. The so-called trade-off curve is defined by the set of "non-inferior" solutions, representing the set of options that are better, regardless of the weights assigned to the different objectives. For example, on this curve, the option called “no hydro” is better than the option “wind”, in terms of both economic cost and biodiversity loss.

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

**Figure 7** Trade-off curves for economic costs versus (a) biodiversity loss; and (b) health impacts

*Source: Meier and Munasinghe 1994*
A quite different trade-off curve was derived between health impacts and average incremental cost, as illustrated in Figure 7 (b). Note that the point "iresid" on the trade-off curve (which calls for the use of low sulphur imported fuel oil at diesel plants), is better than the use of flue gas desulphurisation systems (point "FGD") -- in terms of both economic cost and environment.

Conclusions of Example 3

This example draws several useful conclusions. First, the results indicate that those impacts for which valuation techniques are relatively straightforward and well-established -- such as valuing the opportunity costs of lost production from inundated land, or estimating the benefits of establishing fisheries in a reservoir -- tend to be quite small in comparison to overall system costs, and their inclusion into the benefit-cost analysis does not materially change results. Second, even in the case where explicit valuation may be difficult, such as in the case of mortality and morbidity effects of air pollution, implicit valuation based on analysis of the trade-off curve can provide important guidance to decision-makers. Third, the example indicated that certain options were in fact clearly inferior, or clearly superior, to all other options when one examines all impacts simultaneously. For example, the high dam version of the Kukule hydro project can be safely excluded from all further consideration here, as a result of poor performance on all attribute scales (including the economic one). Fourth, the results indicate that it is possible to derive attribute scales that can be useful proxies for impacts that may be difficult to value. For example, use of the biodiversity loss index, and the population-weighted incremental ambient air pollution scale as a proxy for health impacts permitted a number of important conclusions that are independent of the specific economic value assigned to biodiversity loss and health effects, respectively.

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

5.4 Local-project scale: Hydroelectric power

The procedures for conventional environmental and social assessment at the project/local level (which are now well accepted world wide), may be readily adapted to assess the environmental and social effects of micro-level activities (World Bank 1998). The OECD (1994) has pioneered the 'Pressure-State-Response' framework to trace socio-economic-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). The focus here is on local pressures, but bearing in mind that climate change impacts would
eventually exacerbate the local impacts – the examples are useful because the same analytical techniques may be applied to deal with the impacts of both local and global environmental drivers on key sustainable development indicators.

Specific methods for economic valuation of environmental and social impacts are described in Annex 2. The practical application of such techniques were illustrated in the previous example. When valuation is not feasible for certain impacts, MCA may be used.

**Example 4: Comparison of hydroelectric power projects**

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

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

**Environmental, social and economic indicators**

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

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

The project costs are available for each site, from which the critical economic indicator – average cost per kWh per year – may be estimated (for details, see Ceylon Electricity Board (CEB) 1987, 1988, 1989). The annual energy generation potential at the various sites ranges from about 11 to 210 GWh (see Table 5). All three variables, the biodiversity
Points of departure from the TAR

loss index, number of people resettled, and generation costs, are divided by the amount of electrical energy generated. This scaling removes the influence of project size and makes them more comparable.

Table 5. Multi-criteria indexing of hydropower project options

<table>
<thead>
<tr>
<th>Hydro Site</th>
<th>Annual Generation Gwh</th>
<th>Generation cost AVC/KWh/yr Rank</th>
<th>Persons Resettled RE/KWh/yr Rank</th>
<th>Biodiversity loss BDI/KWh/yr Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGRA003</td>
<td>28</td>
<td>12.1</td>
<td>16</td>
<td>11.07</td>
</tr>
<tr>
<td>DIYA008</td>
<td>11</td>
<td>15.8</td>
<td>18</td>
<td>2.39</td>
</tr>
<tr>
<td>GING052</td>
<td>159</td>
<td>12</td>
<td>15</td>
<td>0.6</td>
</tr>
<tr>
<td>GING053</td>
<td>210</td>
<td>16.4</td>
<td>19</td>
<td>5.77</td>
</tr>
<tr>
<td>GING074</td>
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Source: CEB (1987); CEB (1988); Meier and Munasinghe (1994)

Notes: Average generation costs (AVC), biodiversity loss index (BDI), and number of resettled people (RE) by hydroelectricity project. All indices are per kWh per year. Numbers of people resettled and biodiversity loss index are scaled for convenience (by multipliers $10^{-5}$ and $10^{-9}$ respectively).

Conclusions of Example 4

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

From the table, it is clear that on a per kWh per year basis, the projects named AGRA003 and KALU075 have the highest and lowest biodiversity loss index. HEEN009 and MAGA029 have the highest and lowest numbers of resettled people, and MAHA096 and GING074 have the highest and lowest average generation costs, respectively. Some important comparisons may be made. For example, KALU075 is a relatively large project where the costs are low, whereas MAHA096 is a smaller scheme with much higher costs.
with respect to all three indices. Another simple observation is that a project like KELA071 fully dominates GING053, since the former is superior in terms of all three indicators. Similar comparisons may be made between other projects.

This type of analysis gives policymakers some idea about which project is more favourable from a sustainable energy development perspective. Suppose we arbitrarily give all the three objectives an equal weight. Then, each project may be ranked according to its absolute distance from the origin of the three axes, as shown in Figure 8. For example, rank 1 is given to the one that is closest to the origin, rank 2 to the second closest and so on. On this overall basis, from a sustainable energy development perspective, project no.5 (GING074) is the most favourable one, whereas the least favourable one is project no.14 (MAHA096).

![Figure 8 Three dimensional MCA of sustainable development indicators for various hydro power options](image)

Source: Morimoto, Munasinghe and Meier (2000)
The strength of this approach lies in its ability to help policy-makers in comparing project alternatives more easily and effectively. The simple graphical presentations are readily comprehensible, and indicate the sustainable development characteristics of each scheme quite clearly. The multi-dimensional analysis supplements the more conventional CBA, based on economic analysis alone. Since each project has different features, assessing them by looking at only one aspect (e.g., generation costs, effects on biodiversity, or impacts on resettlement) could be misleading.

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

6. CONCLUDING REMARKS

Sustainable development and climate change are two important and interlinked challenges facing humankind, in the 21st century. Therefore, they merit careful joint analysis. In this context, many relevant findings emerged from the IPCC TAR process, as documented in the three working group reports, special reports, and other documents like the guidance paper on development, equity and sustainability and proceedings of two expert meetings on climate change and sustainable development. Building on this base, the present paper has sought to provide a starting point for preparations for the fourth assessment report (AR4), by analysing key issues linking sustainable development and climate change, using the sustainomics framework.

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 forces and objectives. The economic system is geared mainly towards improving human welfare (primarily through increases in the consumption of goods and services). The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social system seeks to enrich human relationships and achieve individual and group aspirations.

There is no single overarching framework for sustainable development, but sustainomics attempts to describe ‘a trans-disciplinary, integrative, balanced, heuristic and practical meta-framework for making development more sustainable’. This paper has set out the basic elements of such a framework and applied it to several illustrative, practical case studies involving climate change.

Sustainomics recognizes that the precise definition of sustainable development remains an elusive (and perhaps unreachable) goal. Thus, it pursues the less ambitious strategy of
simply seeking to make development more sustainable, which offers greater promise. Such an incremental (or gradient-based) method is more practical, because many unsustainable activities are often easier to recognize and eliminate. The approach seeks to synthesize key elements from a wide range of disciplines. Methods that cross the economy-society-environment interfaces are also important, including environmental and resource economics, ecological economics, sustainability science, conservation ecology, social capital and inclusion, energetics and energy economics, sociological economics, environmental sociology, cultural economics, economics of sociology, and sociology of the environment. While building on earlier work, sustainomics constitutes a more neutral expression which focuses attention explicitly on sustainable development, and especially issues of concern to the developing world.

Comprehensiveness is an important requirement because both sustainable development and climate change involve every aspect of human activity, including complex interactions among socioeconomic, ecological and physical systems. The scope of analysis needs to extend from the global to the local scale, cover time spans extending to centuries (for example, in the case of climate change), and deal with problems of uncertainty, irreversibility, and non-linearity. The approach must not only integrate the economic, social and environmental dimensions of sustainable development, as well as related methodologies and paradigms in a consistent manner, but also provide balanced treatment of all these elements. Balance is also needed in the relative emphasis placed on traditional development versus sustainability. No single discipline could cope with the multiplicity of issues involved, and therefore a trans-disciplinary framework is required which would address the many facets, from concept to actual practice. Although the current state of knowledge makes it rather difficult to provide a complete definition of sustainomics, this paper has identified some of its key constituent elements and how they might fit together. The basic intention was to sketch out preliminary ideas which would help to stimulate discussion and encouraging further contributions that are needed to flesh out the initial framework.

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

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

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

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

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

The sustainomics framework would encourage crucial changes in the mindset of decision makers, by helping them to focus on the structure of development, rather than just the magnitude of economic growth (conventionally measured). This process would make development more sustainable, through the adoption of environmentally- and socially-friendly strategies that enable us to use natural resource inputs more frugally and efficiently, reduce polluting emissions, and facilitate public participation in social
Integrated SD and CC in the IPCC AR4

decisions. Sustainomics serves as an essential bridge between the traditional techniques of decision making and modern environmental and social analysis, by helping to incorporate ecological and social concerns into the decision making framework of human society. Operationally, it plays this bridging role by helping to map the results of environmental and social assessments (EA and SA) onto the framework of conventional economic analysis of projects. Thus, the approach identifies practical social and natural resource management options that facilitate sustainable development.

The climate change problem fits in quite readily within the broad conceptual framework of sustainomics. Alternative development paths will certainly affect future climate change, and in turn, climate change will have an impact on prospects for sustainable development. This full cycle of cause and effect may be considered within an integrated assessment modelling (IAM) framework -- starting from alternative socio-economic development paths (driven by the underlying forces of population, economy, technology, and governance), through GHG and other emissions, to changes in the physical climate system, to biophysical and human impacts, and back to the socio-economic development paths. Development paths strongly affect the capacity to both adapt to and mitigate climate change in any region. Adaptation reduces the impact of climate stresses on human and natural systems, while mitigation lowers potential greenhouse gas emissions. To summarise, both the climate and sustainable development domains interact in a dynamic cycle, characterized by significant time delays. Thus climate change impacts are part of the larger question of how complex social, economic, and environmental subsystems interact and shape prospects for sustainable development.

Decision makers are beginning to show more interest in the assessment of how serious a threat climate change poses to the future basis for improving human welfare. First, global warming poses a significant potential threat to the future economic well-being of large numbers of human beings. Second, climate change could also undermine social welfare and equity in an unprecedented manner. In particular, more attention needs to be paid to the vulnerability of social values and institutions, which are already stressed due to rapid technological changes. Furthermore, both intra- and inter-generational equity are likely to be worsened. Although relevant information is unavailable, on global scale phenomena like climate change, some historical evidence based on large scale disasters like El Nino provide useful insights. Inequitable distributions are not only ethically unappealing, but also may be unsustainable in the long run. Third, the environmental viewpoint draws attention to the fact that increasing anthropogenic emissions and accumulations of GHGs might significantly perturb a critical global subsystem – the atmosphere. Changes in the global climate (e.g., mean temperature, precipitation, etc.) could also threaten the stability of a range of critical, interlinked physical, ecological and social systems and subsystems.

When considering climate change response options, several principles and ideas from environmental economics would be useful – these include the polluter pays principle, economic valuation, internalization of externalities, and property rights. From the social equity viewpoint, the polluter pays principle (mentioned above) is based not only on economic efficiency, but also on fairness. An extension of this idea is the principle of recompensing victims – ideally by using the revenues collected from polluters. There is also the moral/equity issue concerning the extent of the polluters’ obligation to
Points of departure from the TAR

compensate for past emissions (i.e., a form of environmental debt). Several concepts from contemporary environmental and social analysis are also 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.

Integrated sustainable development and climate change policies must take into account, the powerful economywide reforms in common use – including both sectoral and macroeconomic adjustment policies which have widespread effects throughout the economy. The highest priority needs to be given to finding ‘win-win policies’, which promote all three elements of sustainable development (economic, social and environmental). With other policies, trade-offs among different objectives need to be analysed. Economywide policies that successfully induce growth, could also lead to environmental and social harm, unless the macro-reforms are complemented by additional environmental and social measures. The sustainomics approach helps to identify and analyse economic-environmental-social interactions, and formulate integrated sustainable development and climate change policies, by linking and articulating these activities explicitly through the action impact matrix (AIM) method.

From a policy perspective, the effectiveness of climate policies can be enhanced when they are integrated with broader strategies designed to make national and regional development paths more sustainable. This occurs because climate impacts, climate policy responses, and associated socio-economic development will affect the ability of countries to achieve sustainable development goals, while the pursuit of those goals will in turn affect the opportunities for, and success of, climate policies. In particular, the socio-economic and technological characteristics of different development paths will strongly affect emissions, the rate and magnitude of climate change, climate change impacts, the capability to adapt, and the capacity to mitigate climate. There are opportunities for countries acting individually, or in cooperation with others, to reduce costs of mitigation and adaptation and realize benefits associated with achieving sustainable development.

The paper also illustrates these concepts, by applying them to case studies involving climate change and energy problems across the full range of spatial scales. At the global-transnational level, the first example examines the interplay of optimality and durability in determining appropriate global GHG emission target levels. At the level of national-economywide policies, the second case study describes how the action impact matrix (AIM) may be used for policy analysis, while the fourth sets out approaches for restructuring growth to make long term development more sustainable. On the subnational-sectoral scale, the third case outlines methods for improving energy sector decision making (including GHG mitigation) in Sri Lanka. Finally, at the project-local level, multi-criteria analysis is applied to compare small hydroelectric power projects, using relevant economic, social and environmental indicators.
ANNEX 1
Climate Change and Sustainable Development Linkages:
Extracts from the IPCC Third Assessment Report

A1.1. Conceptual overview of linkages between climate change and sustainable development

- Climate change and sustainable development interact in a complex, dynamic cycle, characterised by significant time delays and feedbacks (SYR, Fig.1.1)
- The three major dimensions of sustainable development are economic, social and environmental. Key issues such as climate change, poverty, equity, and sustainability, can be related to all three dimensions (SYR, Fig. 8.3, and Section 8.26)
- Climate change impacts and responses are part of the larger question of how complex social, economic, and environmental sub-systems interact and shape prospects for sustainable development. There are multiple links (SYR, Section 1.9)
- In a broader context, equity and fairness are important elements of the social dimension, while efficiency is a crucial factor in the economic dimension of sustainable development. The impetus of sustainable development provides a crucial reason for finding efficient and equitable solutions to the problem of global warming, especially with regard to future generations (WG3/TAR, Section 10.4.5).
- Climate change and sustainable development have largely separate scientific discourses which need to be brought together (WG3/TAR, Section 2.2, Section 10.3)
- The effectiveness of climate policies can be enhanced when they are integrated with broader strategies designed to make national and regional paths more sustainable (SYR, Fig.1.10)
- Enhancement of adaptive capacity involves similar requirements as promotion of sustainable development (WG2/TAR, Section 18.6).
- Climate mitigation policies may promote sustainable development when they are consistent with broader societal objectives, e.g. those relating to development, sustainability and equity (WG3/TAR, SPM, Chapter 2, SYR 3.37).

A1.2. Consequences of climate change impacts for sustainable development prospects, in various sectors, systems, and regions.

Food and water
- Climate change may lead to impacts on forestry by changes in forest and species distribution and in productivity due to changes in temperature and extreme weather events, and carbon dioxide concentrations. Climate change is likely to increase global timber supply and enhance existing market trends towards rising market share in developing countries (WG2/TAR, Section 5.6.3).
- Even though increased CO₂ concentration can stimulate crop growth and yields that benefit may not always overcome the adverse effects of excessive heat and drought (WG2/TAR, TS).
- Food security in some countries may be worsened by climate change while it may be improved in others (WG2/TAR, Chapter 7, SYR 3.21).
Points of departure from the TAR

- Projected climate change could further decrease streamflow and groundwater recharge and water quality in many water-stressed countries – e.g., in central Asia, southern Africa, and countries around the Mediterranean Sea – but may increase it in some others. Climate change complicates existing water resources management practices by adding uncertainty (WG2/TAR, TS, SYR 2.24, 3.22, 8.19).

Energy, industry and transportation

- Hydropower generation is the energy source most likely to be impacted, since it is sensitive to the amount, timing, and geographical pattern of precipitation as well as temperature (rain or snow, timing of melting). Where they occur, reduced stream flows are expected to negatively impact hydropower production; while greater stream flows, if timed correctly, might help hydroelectric production. (WG2/TAR, Section 7.3)

- Increased cloudiness can reduce energy production from some solar energy facilities. Wind energy production would be reduced if wind speeds increase above or fall below the acceptable operating range of the technology. Changes in growing conditions could affect production of biomass, as well as prospects for carbon sequestration in soils and forest resources. (WG2/TAR, Section 7.3)

- Climate change may have (local and regional) impacts on availability of resources to industry as a result of changes in average temperature, precipitation patterns and weather disaster frequencies, in particular, availability of water (as a resource, energy source or for cooling) and renewable inputs (industrial and food crops) may be affected. (WG3/SRTT, Section 9.2).

- A future climate with more summer rain days, somewhat higher rain rates, and more rainstorms would increase total vehicular accidents and total injuries in vehicular accidents, reduce travel on public transportation systems, and cause more aircraft accidents and delays (WG2/TAR, Section 7.3)

- Coastal transport infrastructure can be damaged by a combination of sea-level rise and increased storminess (WG2/TAR, Section 13.2)

- Fluctuating water levels at sea or rivers may also affect the steady supply of resources to industrial facilities, as evidenced by the impact of extremely high water levels on river bulk transport on the Rhine river system. (WG3/SRTT, Section 9.2)

Human settlements

- Human settlements have been affected by recent increases in floods, droughts, rising socio-economic costs related to weather damage and regional variation in climate. This suggests the increasing vulnerability of human settlements to climate change (SYR 2.25-27)

- The ability to cope with negative impacts or to take advantage of positive impacts is likely to be greater among advantaged groups than among disadvantaged groups, both within regions and between regions. As a result, climate change has the potential to enlarge equity-related gaps in human settlements and systems. (WG2/TAR, Chapter 7)

- Physical infrastructure or services may be directly affected by flooding, sea level rise (WG2/TAR, Chapter 7), permafrost melting.
• Although most indigenous peoples are highly resilient, the combined impacts of climate change and globalisation create new and unexpected challenges. (WG2/TAR, Section 16.2.8)

• The capacity of permafrost to support buildings, pipelines and roads decreases with atmospheric warming, so that pilings fail to support even insulated structures (WG2/TAR Section 16.2.8)

• Degradation of coral reefs, including coral bleaching, due to climate impacts can have long-term socioeconomic consequences due to changed fish species mix and decreased fish stocks, and negative effects on tourism as a result of degraded reefs. Degradation of reefs will also lead to diminished natural protection of coastal infrastructure against high waves and storm surges on low-lying atolls (WG2/TAR, Section 6.5.4)

**Human health**

• Overall climate change is projected to increase threats to human health, access to adequate food, clean water and other resources, particularly in lower income population’s predominantly within tropical/sub tropical countries (SYR 3.17, 3.33)

• Some health impacts would result from changes in the frequencies and intensities of extremes of heat and cold, of floods and droughts. Other health impacts would result from the impacts of climate change upon ecological and social systems, and would include changes in infectious disease occurrence, in local food production and nutritional adequacy, in concentrations of local air pollutants and aeroallergens, and the various health consequences of population displacement and economic disruption (WG2/TAR, Chapter 9, SYR 2.28).

• Flooding may become more frequent with climate change and can affect health through the spread of disease (WG3/SRTT, Section 14.4.1).

• Health impacts will tend to occur unevenly in the world - and the impacts in poorer populations, especially in the least developed countries, will often be augmented by the heightened vulnerability of those populations (WG2/ TAR, Section 9.14)

**Natural ecosystems (terrestrial, freshwater and marine systems)**

• Changes in terrestrial and marine ecosystems are closely linked to changes in climate and vice versa (SR 8.13-16)

• Studies have shown that, in the event of an adverse impact on vegetation due to climate change, the forest dependent communities will be adversely affected through loss or change in forest area and diversity, and through forest dieback. (WG3/SRTT, Section 12.7, SR 3.18).

• Climate change would exacerbate the continuation of land degradation and desertification in many areas (SYR 8.18)

• Solar radiation, temperature and available water affect photosynthesis, plant respiration and decomposition, thus climate change can lead to changes in net ecosystem productivity (WG1/TAR, Section 3.2.2, SYR 3.19)

• Natural ecosystems provide many goods and services which relate to sustainable development, such as wildlife (e.g. pest control, pollinators, seed dispersal, soil maintainers, subsistence hunting, recreation, non-market values), rangelands, forests (e.g. timber, tourism, carbon storage, non-wood products), lakes, streams and wetlands (e.g. food and fiber, carbon sink), etc. (WG2/TAR, Chapter 5, SYR 3.20)
• Large-scale impacts of global warming on the oceans will include increases in sea level and sea-surface temperature; decreases in sea-ice cover; and changes in salinity, alkalinity, wave climate and ocean circulation. Collectively these changes will have profound impacts on the status, sustainability, productivity and biodiversity (e.g. coral reefs and fish population’s) of the coastal zone and marine ecosystems. (WG2/TAR, Chapter 6, SYR 2.22-23)

• Climate change represents an additional stress on systems already affected by increased resource demands. In coastal areas, where a large part of the global population lives, climate change can cause inundation of wetlands and lowlands, erosion and degradation of shorelines and coral reefs, increased flooding and salinisation of estuaries and freshwater aquifers. (WG3/SRTT, Section 6.1, SYR 3.23-24)

### Aggregate socio-economic impacts

• Most coastal impacts of climate change will impinge on collective goods and systems, such as food and water security, biodiversity and human health and safety. These impacts could affect commercial interests indirectly, but usually the strongest and most direct incentives to adapt are with the public sector (WG3/SRTT, Section 15.4)

• With a small temperature increase, there is medium confidence that aggregate market sector impacts would amount to plus or minus a few percent of world GDP, while there is low confidence that aggregate nonmarket impacts would be negative. Most studies of aggregate impacts find that there are net damages at the global scale beyond a medium temperature increase, and that damages increase from there with further temperature increases. (WG2/TAR, Section 19.4, SYR 3.25).

• Hazards associated with climate change can undermine progress toward sustainable development (SYR 3.35)

### A1.3. Consequences of climate change response actions (mitigation, adaptation, and vulnerability reduction) for sustainable development prospects in various sectors, systems, and regions

#### Food and water

• Appropriately designed forestry mitigation and adaptation projects contribute to other environmental impacts as biodiversity conservation, watershed protection, and socio-economic benefits to urban and rural populations through access to forest products and creation of jobs, especially in rural areas ultimately promoting sustainable development. (WG3/SRTT, Executive Summary, Chapter 12)

• Although plantations usually have lower biodiversity than natural forest, they can reduce pressure on natural forests, leaving greater areas to provide for biodiversity and other environmental services (WG3/TAR, Section 4.4); Promotion of forestry-sector mitigation projects and the accompanying technology component would require careful attention as its adoption could impact biodiversity and the watershed role of forests and further affect the poorest and indigenous communities. (WG3/SRTT, Section 12.5)

• A range of adaptation options can be employed in the agricultural sector to increase the flexibility and adaptability of vulnerable systems, and reverse trends that increase
vulnerability. Many of these attempts to abate climate change will be of immediate benefit, and can therefore be considered “no-regret” technologies. (WG3/SRTT, Section 11.2)

- Options to reduce vulnerability of agriculture to climate change (e.g. drought resistant varieties) can have multiple benefits, e.g. reducing vulnerability to current climate variability (WG2/TAR, Chapter 5)
- Technology transfer strategies in the forestry sector for promoting mitigation options, apart from reducing greenhouse gas (GHG) emissions or enhancing carbon sinks, have the potential to provide other tangible socio-economic and local and global environmental benefits, contributing to sustainable development. (WG3/SRTT, Section 12.1)
- Adaptations in agriculture are possible, but they will not happen without considerable transition costs and equilibrium (or residual) costs. (WG2/TAR, Section 18.6)
- The effectiveness of technology transfer in the agricultural sector in the context of climate change response strategies would depend to a great extent on the suitability of transferred technologies to the socio-economic and cultural context of the recipients, considering development, equity, and sustainability issues. This is particularly relevant when applied to North-South technology transfers in this sector (WG3/SRTT, Executive Summary, Chapter 1)

**Energy, industry and transportation**

- The very likely direct costs for fossil fuel consumption are accompanied by very likely environmental and public health benefits associated with a reduction in the extraction and burning of the fuels. GHG mitigation policies reducing [the growth in] demand for fossil fuels could result in several ancillary benefits: slower rate of depletion, less air and water pollution, reduced import dependency; Uptake of new, high-efficiency technologies could lead to enhanced skills levels and technological capacity in developing countries (WG3/TAR, Chapter 9)
- Successful technology transfer strategies link climate change goals with measures that produce these companion benefits (WG3/SRTT, Section 7.1). While the primary emphasis is on increased efficiency, fuel switching also can lead to lower GHG emissions (WG3/SRTT, Section 7.1). Many of the technologies that mitigate GHG emissions also help adapt to the potential effects of climate change (WG3/SRTT, Section 7.2.3).
- Energy resource development and increase in energy R&D to assist accelerating development and deployment of advanced environmentally friendly sound energy technologies is needed (SYR 9.33)
- Certain climate-change-related actions can be beneficial to developing countries. For example, measures to improve energy efficiency could support their economic growth, and widen the opportunities for transferring more advanced energy technologies that could bring multiple benefits, while also limiting their greenhouse gas emissions. (WG3/SRTT, Section 3.2)
- Adaptation to reduced navigation opportunities can be realised through enhanced water-level managements, increased dredging, or smaller ships (WG2/TAR, Section 13.3). Such options can have multiple benefits, e.g. reduced vulnerability to natural climate vulnerability.
Points of departure from the TAR

- Transport policies can have co-benefits in terms of reduced air emissions, reduced congestion, fewer traffic crashes, less noise and less road damage (WG3/TAR, Section 9.2.8).

**Human settlements**
- Humans have shown a capacity to adapt to long-term mean climate conditions, but there is less success in adapting to extreme and year-to-year variations in climatic conditions (SYR 5.9)
- Adaptation options include improved land-use planning; planning and design of new housing with low environmental impacts and less exposed to flood and other hazards; improving water, sanitation, and electricity supply systems; improving flood control; diversifying economic activities; building efficient environmental institutions. These options are likely to have multiple benefits. (WG2/TAR, Chapter 7)
- A systems, or whole-building approach, can achieve both mitigation and adaptation objectives through the optimal integration of land use, building design, equipment and material choices and recycling strategies. (WG3/SRTT, Section 7.2).
- Adaptation in fishery management such as measures that can promote sustainable fishery (improved and expanded monitoring to obtain information for better management of fisheries, sharing of this information, modification of fishing industry efforts, practices and investment to match biological productivity and responses to climate change, and protection of spawning areas and habitat) (WG2/TAR, Chapter 6) can have multiple benefits.
- Coastal-adaptation technologies can provide an important contribution to the sustainable development in coastal zones, but their effectiveness depends strongly on the economic, institutional, legal and socio-cultural contexts in which they are implemented. Furthermore, climate change is but one of the many interacting stresses in coastal zones (WG3/SRTT, Section 15.7.2).

**Human health**
- Adaptation options include: investments in public health training programmes, disease surveillance, sanitation systems, disease vector control, immunizations, resources to respond to disease outbreaks and resources to diagnose and treat disease are important components of efforts to (re-)build public health infrastructure (WG2/TAR, Chapter 9). Such health adaptation options to climate change would promote health generally, regardless of the effects of climate change.
- Ancillary benefits [of GHG mitigation actions] related to public health accrue over the short term, and under some circumstances can be a significant fraction of private (direct) mitigation costs (WG3/TAR, Section 8.2.4).

**Natural ecosystems (terrestrial, freshwater and marine systems)**
- Greenhouse gas emissions reduction (mitigation) actions would lessen the pressures on natural and human systems for climate change (SYR 6.10)
- Adaptation options [in ecosystem management] could produce multiple benefits in the form of reduced climate change vulnerability and promotion of sustainable development (WG2/TAR, Chapter 5).
• Some options for adaptation (e.g. in the areas of wood product supply, and water use and management) may have adverse effects on natural ecosystems. (WG/TAR, Chapter 5)

Aggregate socio-economic impacts
• Adaptation is a necessary strategy at all scales to complement climate change mitigation efforts. Together they can contribute to sustainable development objectives (SYR 6.13-18, 9.40)
• Adaptation measures to changing climatic conditions are more likely to be implemented if they are consistent with or integrated with decisions or programmes addressing non-climatic stresses. Vulnerabilities associated with climate change are rarely experienced independently of non-climatic conditions. (WG2/TAR, Section 18.8)
• In the absence of emissions trading between Annex B countries, the majority of global studies show reductions in projected GDP of about 0.2 to 2% in 2010 for different Annex II regions. With full emissions trading between Annex B countries, the estimated reductions in 2010 are between 0.1 and 1.1% of projected GDP. (WG3/TAR, SPM)
• Emission constraints in Annex I countries have well established, albeit varied “spillover” effects on non-Annex I countries. Oil-exporting, non-Annex I countries: Analyses report costs differently, including, inter alia, reductions in projected GDP and reductions in projected oil revenues. Other non-Annex I countries may be adversely affected by reductions in demand for their exports to OECD nations and by the price increase of those carbon-intensive and other products they continue to import. These countries may benefit from the reduction in fuel prices, increased exports of carbon-intensive products and the transfer of environmentally sound technologies and know-how. (WG3/TAR, SPM)
• Mitigation actions to stabilise atmospheric concentrations of greenhouse gases at lower levels would generate greater benefits in terms of less damage (SYR 6.11)

A1.4. Synergies and tradeoffs between different sustainable development strategies, and options for increasing adaptive capacity and reducing vulnerability to climate change, in various sectors, systems and regions

Food and water
• A majority of these [adaptation/mitigation technology transfer] efforts [in forestry] have emerged independently of the climate change-related debates. (WG3/SRTT, Section 12.3.2)
• An analysis of the literature suggests that C mitigation strategies can be pursued as one element of more comprehensive strategies aimed at sustainable development, where increasing C stocks is but one of many objectives. (WG3/TAR, Chapter 4)
• Development of drought resistant varieties can reduce vulnerability to natural climate variability as well as change (WG2/TAR, Chapter 5)
• Adaptation technologies which involve institutional infrastructures (for example in agriculture, health and human settlement planning) could be integrated with other
parts of efforts to alleviate poverty and promote development (WG3/SRTT, Section 4.10.1)

- Ability to adapt is affected by institutional capacity, wealth, management philosophy, planning time scale, organizational and legal framework, technology, and population mobility. (WG2/TAR, Section 18.6). These factors also determine the effectiveness of water management regardless of climate change.

- There are numerous “no regrets” water policy changes, which would provide benefits by addressing growing water demands and reducing risks associated with hydrological variability, which in turn would reduce vulnerability to climate change (WG2/TAR, Chapter 4)

**Energy, industry and transportation**

- Recent major innovations in infrastructure design such as linking urban transport to land-use patterns, zoning, increase access to jobs and shops, comprehensive and integrated planning strategies have lead to reduction of urban pollution with possible climate change benefits as they reduce the reliance on automobile transportation (WG3/SRTT, Section 8.2.4).

**Human settlements**

- Local capacity to limit environmental hazards or their health consequences in any settlement generally implies local capacity to adapt to climate change, unless adaptation implies particularly expensive infrastructure investment. There are many techniques that can contribute towards better environmental planning and management including: market-based tools for pollution control, demand management and waste reduction, mixed-use zoning and transport planning (with appropriate provision for pedestrians and cyclists), environmental impact assessments, capacity studies, strategic environmental plans, environmental audit procedures and state of the environment reports (WG2/TAR, Section 7.5.2)

- Lessons from “Sustainable cities” activities may be applicable to future climate change adaptation responses (WG2/TAR, Section 7.5.3).

- Adaptation options are more acceptable and effective when incorporated into coastal zone management, disaster mitigation programs, land use planning, and sustainable development strategies. (WG2/TAR, Section 18.6). Conversely, such strategies can enhance adaptive capacity.

- Socio-economic factors such as technical and institutional abilities, economic wealth, and cultural characteristics determine a society’s adaptive capacity in coastal areas (WG2/TAR, Chapter 6, WG3/SRTT, Section 15.7). Hence, strategies pursuing sustainable development in these areas can also enhance adaptive capacity.

- Policies and practices that are unrelated to climate but which do increase a system’s vulnerability to climate change are termed “maladaptation”. Examples of maladaptation in coastal zones include investments in hazardous zones, inappropriate coastal-defence schemes, sand or coral mining and coastal-habitat conversions. (WG3 SRTT Section 15.2.2)

**Human health**

- Public health structure, water and sanitation infrastructure, nutritional status of the population, local food supplies and distribution systems, education levels and access
to information, exposure to disease vectors, air quality, urban heat island effects, existence of early warning systems for extreme weather events, concentration of people in high risk areas, flood control measures, poverty are all determinants of health (WG2/TAR, Chapter 9). Addressing these issues will also reduce vulnerability to climate change.

**Natural ecosystems (terrestrial, freshwater and marine systems)**

- Adapting to declines in wildlife populations by establishing parks, refuges, and reserves rarely takes into account potential climate change [and associated migration needs] (WG2/TAR, Chapter 5)
- Resilience to climate change is but one of many considerations influencing decisions on forestry next to biodiversity and other ecological benefits such as watershed protection, soil erosion protection, and prevention of desertification. (WG3/SRTT, 12.2.1)

**Aggregate issues**

- Various development paths, sustainable or otherwise, will shape future vulnerability to climate change and climate impacts may affect prospects for sustainable development in different parts of the world (WG2/TAR, TS, Section 7.2.3).
- Population living in poverty have relatively low capacity to adapt to, and cope with climate change impacts such as those on water, and hence poverty eradication can reduce vulnerability to these impacts (WG2/TAR, Chapter 7)

**A1.5. Synergies and tradeoffs between different sustainable development strategies, and options for increasing mitigative capacity and mitigating GHG emissions, in various sectors, systems and regions**

**Food and water**

- Improvements in agricultural yields, dietary changes that influence meat production, cattle population, and in turn, grassland cover in combination with demographic changes can lead in some scenarios to a considerable “greening” of the planet, without climate change concerns taken into account. (WG3, SRES, Chapter 4)
- Possible conflicts of land use for sustainable food production, soil nutrient depletion, water availability, and biodiversity need to be addressed. (WG3/TAR, Section 3.6.1)
- Agriculture will be heavily influenced by climate change. Sustainable agricultural development is an ongoing priority for all countries. Transfer of adaptation and mitigation technologies has significant benefits independent of climate change consideration, but is even more relevant, now climate change will offer greater challenges and development opportunities for agricultural systems (WG3/SRTT, Section 11.6)
- Reducing nitrogen losses from fertilisation (e.g. slow release fertilisers, organic manures, nitrification inhibitors) would improve nitrogen availability for crops, but also reduce nitrous oxide emissions (WG3/TAR, Section 3.6.4)
- In order for agricultural production to be undertaken in a more sustainable manner, one can use husbandry methods and management techniques to minimize the inputs
of energy, synthetic fertilizers and agri-chemicals on which present industrialized farming methods depend. (WG3/TAR, Section 3.6.1)

- Hydropower remains the most developed renewable resource worldwide. Large-scale hydropower plant developments can have high environmental and social costs such as loss of fertile land, methane generation from flooded vegetation, and displacement of local communities. (WG3 TAR Section 3.8.3)
- Methane emissions from domestic and industrial wastewater disposal contribute about 10% of global anthropogenic methane sources (30-40 Mt annually). Industrial wastewater, mainly from pulp and paper and food processing industries, contributes more than 90% of these emissions, whereas domestic and commercial wastewater disposal contributes about 2 Mt annually. (WG3/TAR, Section 3.7.2.5)

**Energy, industry and transportation**

- In some long-term scenarios (e.g. SRES B1, A1T) GHG emissions from the energy sector are eventually declining on the basis of technological innovation, economic structural changes and demographic developments unrelated to climate change (WG3, SRES, Chapter 4)
- In many places, renewable energy technologies seem to offer some of the best prospects for providing needed energy services while addressing the multiple challenges of sustainable development, including air pollution, mining, transport, and energy security. (WG3/TAR, Section 1.4.2.1)
- Efforts mainly driven by other concerns than climate change have led to technological options (improved technology design and maintenance, alternative fuels, vehicle use change, and modal shifts) and non-technical options (transport reduction, and improved management systems) that can reduce GHG emissions significantly (WG3/SRTT, Executive Summary, Chapter 8).
- Adoption of opportunities including greenhouse gas reducing technologies and measures may require overcoming barriers through the implementation of policy measures (SYR 7.5-7.8, 8.24)
- Current energy supply technology transfer is primarily driven by objectives of economic development and international competitiveness. Climate change objectives and in particular the reduction of CO$_2$ emissions do not play a significant role. This does not imply that energy supply technology transfer has no effect on climate change, but that such effects are coincidental rather than intended. (WG3/SRTT, Section 10.3.1)
- There is scope where infrastructure is developing rapidly to implement planning measures that encourage more sustainable transport patterns, avoiding the pollution, congestion, higher accident rates, and also GHG emissions associated with cars (WG3/TAR Section 5.3.2).
- Three policy strands intend to lead from the status quo to sustainability: (a) “best practice” in urban transport policy, combining combining land-use management strategies with advanced road traffic management strategies, environmental protection strategies and pricing mechanisms, (b) in addition investments in transit, pedestrian and bicycle infrastructure, and (c) steep year-by-year increases in fuel prices, full-cost externality pricing for motor vehicles, and ensuring use of high-efficiency, low-weight and low-pollution vehicles in cities (WG3/ TAR, Section 3.4.4)
• Significant achievements have been made in developing transport systems that reduce GHG emissions though the development of other concerns such as performance gains, safety, and energy intensity improvements has been paramount in their development. Introducing various options to mitigate GHG emissions may require justification of other objectives other than GHG mitigation such as competitiveness, security concerns, and improvement of quality of life or local environment improvement. (WG3/SRTT, Section 8.2).

**Human settlements**

• Hundreds of technologies and measures exist in buildings, households and services that can improve the energy efficiency of appliances and equipment as well as building structures in all regions of the world (WG3/TAR, TS). Improving energy efficiency can be pursued independent of climate change concerns, in order to reduce energy costs.

**Human health**

• Public health concerns related to urban air pollution increasingly lead to abatement of sulfur emissions, also in developing countries. If, in addition to desulphurisation of flue gases, this is achieved by energy conservation, interfuel substitution from high to low sulfur gases, associated GHG emissions reductions will be achieved (WG3, SRES, Chapters 3, 4 and 5).

• The formal health sector is not substantively involved in the reduction of greenhouse gas emissions – other than incidentally via participation in society-wide improved energy efficiency (hospital building design, institutional energy-use policies, etc.), and by promoting alternative energy-saving systems of transport and mobility to increase physical activity levels. (WG3/SRTT, Section 14.1)

**Natural ecosystems (terrestrial, freshwater and marine systems)**

• High incomes in some scenarios also increase the demand for environmental amenities. Hence, “demand” for forests also increases with economic growth, and the expected rent of forest land is assumed to increase. These rising rents eventually reduce the rate of deforestation and increase the area of managed tree-covered land (WG3, SRES, Section 4.4.9.1).

**Aggregate socio-economic changes and strategies**

• Climate policy, and the impacts of climate change, will have significant implications for sustainable development at both the global and sub-global levels. In addition, policy and behavioural responses to sustainable development issues may affect both our ability to develop and successfully implement climate policies, and our ability to respond effectively to climate change. In this way, climate policy response will affect the ability of countries to achieve sustainable development goals, while the pursuit of those goals will in turn affect the opportunities for, and success of, climate policy responses. (WG3/TAR, Section 2.2.3)

• GHG emissions are likely to be reduced by other policies for the sustainable use of resources, such as land, forest ecosystems, mineral resources, water, and soil. Instruments may include direct planning, regulations, establishing property rights and
obligations, information, education, and persuasion, and a broad range of prices to support or influence the innovation process to encourage dematerialization (SRES 3.7.2).

- Decisions about technology, investment, trade, poverty, biodiversity, community rights, social policies, or governance, which may seem unrelated to climate policy, may have profound impacts upon emissions, the extent of mitigation required, and the cost and benefits that result. Conversely, climate policies that implicitly address social, environmental, economic, and security issues may turn out to be important levers for creating a sustainable world (WG3/TAR, Section 1.4.1)

- Alternative pathways could be considered to pursue global sustainability and address issues like decoupling growth from resource flows, for example through eco-intelligent production systems, resource light infrastructure and appropriate technologies, and decoupling well being from production, for example through intermediate performance levels, regionalization of production systems, and changing lifestyles. (WG3/TAR, TS). Such developments have important GHG implications.

- Sustainable development is a context-driven concept and each society may define it differently. Technologies that may be suitable in each of such contexts may differ considerably. This makes it important to ensure that transferred [mitigation] technologies meet local needs and priorities, thus increasing the likelihood that they will be effective. (WG3,SRTT, Section 1.2)

- Approaches that exploit synergies between environmental policies and key notional socio-economic objectives like growth and equity could help to mitigate and reduce vulnerability to climate change as well as promote sustainable development (SYR 8.26)

A1.6. Mutual interlinkages between different overall development paths (that cut across various sectors and systems), including strategies for technology development, diffusion and transfer processes, and climate change responses

**Synergies and trade-offs in sectoral policies**

- Policies governing agriculture and land use and energy systems need to be linked for climate change mitigation. There is a latent demand for low-cost housing, small hydropower units, low-input organic agriculture, local non-grid power stations, and biomass-based small industries. Sustainable agriculture can benefit both the environment and food production. Biomass-based energy plants could produce electricity from local waste materials in an efficient, low-cost, and carbon-free manner. Each of these options needs to be evaluated alongside conventional energy supply and demand alternatives in terms of the impacts and contribution to sustainable development. (WG3/TAR, Section 1.4.2, Chapter 2)

- Trends in inequality, resource consumption and depletion, environmental degradation, population growth and ill-health are closely interrelated and will strongly interact with potential climate change impacts. Such problems cannot be effectively addressed solely by implementing improved intersectoral (energy, agriculture) or public health technologies. Cross-sectoral policies that promote ecologically sustainable development and address underlying driving forces will be essential. (WG3/SRTT, Section 14.4.3)
Role of alternative socio-economic development pathways and system inertia

- Development paths that meet sustainable development objectives may result in lower levels of greenhouse gas emissions (WG3/TAR, SPM, Chapter 2, SYR 9.41).
- [This] comparisons of SRES scenario characteristics imply that similar future emissions can result from very different socio-economic developments, and similar developments of driving forces can result in different future emissions. Uncertainties in future development of key emissions driving forces create large uncertainties in future emissions even with the same socio-economic development paths. (SRES TS 9.1.3).
- Particular sets of technological and behavioral options can be clustered into alternative, internally consistent packages to represent different choices over time and so define different development paths for any economy. Such clusters can give rise to self-reinforcing loops between technical choices, consumer demand, and geographic distributions, which create “lock-in” effects and foreclosures of options in technology and socio-institutional innovations. The time-dependent nature of these choices gives rise to bifurcations and irreversibilities in which the shift from one development path to another entails important economic and political costs. (SRES 3.3.5.)
- The existence of time lags, inertia and irreversibility in the Earth system means that a mitigation action or technology development can have different outcomes, depending on when it is taken (SYR, Chapter 5)
- Technological inertia in less developed countries can be reduced through “leapfrogging”(i.e. adopting anticipative strategies to avoid the problems faced today by industrial societies). (SYR, Chapter 5)
- The challenge of addressing climate change raises an important issue of equity, namely the extent to which the impacts of climate change or mitigation policies ameliorate or exacerbate inequities both within and across nations and regions, and between generations. (SYR Chapter 7)

Synergies in transfer of environmentally sound technologies

- Environmental sustainability, including mitigating and adapting to climate change, can be seen not as a barrier to growth, but as a boundary condition that could stimulate the emergence of a sustainable industrial economy, a process in which technology transfer is likely to play a major role. (WG3/SRTT, Section 5.4.1)
- To the extent that the transfer of technology is seen as an important operational tool for addressing the global climate change problem, it will also have a serious impact on distribution issues. Technology transfer within countries is likely to affect some groups positively at the cost of other groups so clear distribution issues will become evident. If they are ignored there could be negative consequences on achieving technology transfer. (WG3/SRTT, Section 4.10) However, the international equity aspect of climate change impacts and adaptation have received relatively little attention so far.
- Past experience with technology transfer in a variety of sectors can be used to suggest policy tools for providing enabling environments for the transfer of technologies for mitigation and adaptation to climate change that is supportive and sustainable. Evidence exists both of barriers and ways in which barriers can be avoided and overcome. Experience also shows that technology transfer offers many opportunities for sustainable economic and social development. The sustainable use of environmentally sound technologies (ESTs) for climate change has to fulfill not only
social but also economic and development objectives through a complex process of technological change (WG3/SRTT Section 4.1).

**Abbreviations (for IPCC publications)**

- **SPM** - Summary for Policymakers
- **SRES** - Special Report on Emissions Scenarios
- **SRTT** - Special Report on Technology Transfer
- **SYR** - Synthesis Report
- **TAR** - Third Assessment Report
- **TS** - Technical Summary
- **WG2** - Working Group 2
- **WG3** - Working Group 3
A2.1 Indicators

A wide variety of indicators relating to the social, economic and environmental dimensions of sustainable development have been discussed in the literature [e.g., Munasinghe and Shearer 1995; UNDP 1998; World Bank 1998; Liverman et al. 1988; Kuik and Verbruggen 1991; Opschoor and Reijnders 1991; Holmberg and Karlsson 1992; Adriaanse 1993; Alfsen and Saebo 1993; Bergstrom 1993; Gilbert and Feenstra 1994; Moffat 1994; OECD 1994; Azar 1996; UN 1996; Commission on Sustainable Development (CSD) 1998; World Bank 1997]. In particular, we note that measuring the stocks of economic, environmental (natural), human and social capital raises various problems.

Manufactured capital may be estimated using conventional neo-classical economic analysis. As described later in the section on cost-benefit analysis, market prices are useful when economic distortions are relatively low, and shadow prices could be applied in cases where market prices are unreliable (e.g., Squire and van der Tak 1975).

Natural capital needs to be quantified first in terms of key physical attributes. Typically, damage to natural capital may be assessed by the level of air pollution (e.g., concentrations of suspended particulate, 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., Munasinghe 1992; Freeman 1993; Teitenberg 1992).

Social capital is the one that is most difficult to assess (Grootaert 1998). Putnam (1993) described it as ‘horizontal associations’ among people, or social networks and associated behavioural norms and values, which affect the productivity of communities. A somewhat broader view was offered by Coleman (1990), who viewed social capital in terms of social structures, which facilitate the activities of agents in society – this permitted both horizontal and vertical associations (like firms). An even wider definition is implied by the institutional approach espoused by North (1990) and Olson (1982), 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. Recent work has sought to distinguish between social and political capital (i.e., the networks of power and influence that link individuals and communities to the higher levels of decisionmaking). Human resource stocks are often measured in terms of the value of educational levels, productivity and earning potential of individuals.
A2.2 Cost-Benefit Analysis (CBA)

Cost-benefit analysis is an important tool in the economic and financial analysis of projects and for determining their viability. The basic criterion for accepting a project is that the net present value (NPV) of benefits is positive. Typically, \( \text{NPV} = \text{PVB} - \text{PVC} \),

where \( \text{PVB} = \sum_{t=0}^{T} B_t / (1 + r)^t \) ; and \( \text{PVC} = \sum_{t=0}^{T} C_t / (1 + r)^t \).

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

When two projects are compared, the one with the higher NPV is deemed superior. Furthermore, if both projects yield the same benefits (PVB), then it is possible to derive the least cost criterion -- where the project with the lower PVC is preferred. The IRR is defined as that value of the discount rate for which \( \text{PVB} = \text{PVC} \), while \( \text{BCR} = \text{PVB} / \text{PVC} \). The BCR may be interpreted as a measure of 'cost effectiveness', e.g., even if the benefits are not measurable in monetary terms, BCR indicates the gain derived per unit of investment in a project. Further details of these criteria, as well as their relative merits in the context of sustainable development, are provided in (Munasinghe 1992).

If a purely financial analysis is required from the private entrepreneurs viewpoint, then \( B \), \( C \), and \( r \) are defined in terms of market or financial prices, and NPV yields the discounted monetary profit. This situation corresponds to the economist's ideal world of perfect competition, where numerous profit-maximising producers and utility-maximising consumers achieve a Pareto-optimal outcome. However, conditions in the real world are far from perfect, due to monopoly practices, externalities (such as environmental impacts which are not internalised in the private market), and interference in the market process (e.g., taxes). Such distortions cause market (or financial) prices for goods and services to diverge from their economically efficient values. Therefore, the economic efficiency viewpoint usually requires that shadow prices (or opportunity costs) be used to measure \( B \), \( C \) and \( r \). In simple terms, the shadow price of a given scarce economic resource is given by the change in value of economic output caused by a unit change in the availability of that resource. In practice, there are many techniques for measuring shadow prices - e.g., removing taxes, duties and subsidies from market prices (for details, see Munasinghe 1992; Squire and van der Tak 1975).

The incorporation of environmental considerations into the economist’s single valued CBA criterion requires further adjustments. All significant environmental impacts and externalities need to be valued as economic benefits and costs. As explained earlier in the section on indicators, environmental assets may be quantified in physical or biological units. Recent techniques for economically valuing environmental impacts are summarised in Box A.1. However, many of them (such as biodiversity) cannot be accurately valued in monetary terms, despite the progress that has been made in recent years (Munasinghe 1992; Freeman 1993). Therefore, criteria like NPV often fail to adequately represent the environmental aspect of sustainable development.
Capturing the social dimension of sustainable development within CBA is even more problematic. Some attempts have been made to attach ‘social weights’ to costs and benefits so that the resultant NPV favours poorer groups. However, such adjustments (or preferential treatment for the poor) are rather arbitrary, and have weak foundations in economic theory. Other key social considerations like empowerment and participation are hardly represented within CBA. In summary, the conventional CBA methodology would tend to favour the market-based economic viewpoint, although environmental and social considerations might be introduced in the form of side constraints.

**Box A.1. Techniques for economically valuing environmental impacts**

<table>
<thead>
<tr>
<th>BEHAVIOUR TYPE</th>
<th>Conventional market</th>
<th>Implicit market</th>
<th>Constructed market</th>
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<tbody>
<tr>
<td>Actual Behaviour</td>
<td>Effect on Production</td>
<td>Travel Cost</td>
<td>Artificial Market</td>
</tr>
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<td></td>
<td>Effect on Health</td>
<td>Wage Differences</td>
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<td></td>
<td>Defensive or Preventive Costs</td>
<td>Property Values</td>
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<td>Proxy Marketed Goods</td>
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<tr>
<td>Intended Behaviour</td>
<td>Replacement Cost</td>
<td></td>
<td>Contingent Valuation</td>
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<td></td>
<td>Shadow Project</td>
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</tbody>
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**Box A.1. Techniques for economically valuing environmental impacts**

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

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

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

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

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

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

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

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

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

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

*Source:* adapted from Munasinghe (1992)

### A2.3 Multi-Criteria Analysis (MCA)

This technique is particularly useful in situations where a single criterion approach like
CBA falls short – especially when significant environmental and social impacts cannot be
assigned monetary values. MCA is implemented 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 comprehensible, 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 judgements 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 A2.1 is a two dimensional representation of the basic concepts underlying MCA. Consider an electricity supplier, who is evaluating a hydroelectric project that could potentially cause biodiversity loss. Objective $Z_1$ is the additional project cost required to protect biodiversity, and $Z_2$ is an index indicating the loss of biodiversity. The points A, B, C and D in the figure represent alternative projects (e.g., different designs for the dam). In this case, project B is superior to (or dominates) A in terms of both $Z_1$ and $Z_2$ – because B exhibits lower costs as well as less bio-diversity loss relative to A. Thus, alternative A may be discarded. However, when we compare B and C, the choice is more complicated since the former is better than the latter with respect to costs but worse with respect to biodiversity loss. Proceeding in this fashion, a trade-off curve (or locus of best options) may be defined by all the non-dominated feasible project alternatives such as B, C and D. Such a curve implicitly places both economic and environmental attributes on a more equal footing.
Further ranking of alternatives is not possible without the introduction of value judgements (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). Each such equi-preference curve indicates the locus of points along which society is indifferent to the trade-off between the two objectives. The preferred alternative is the one that yields the greatest utility – i.e., at the point of tangency D of the trade-off curve with the best equi-preference curve (i.e., the one closest to the origin).

Since 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 bio-diversity 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 Z3.

A2.4 Linking sustainable development issues with conventional decision making

Figure A2.2 provides an example of how environmental assessment is combined with economic analysis. The right-hand side of the diagram indicates the hierarchical nature of conventional decision making in a modern society. The global and international level consists of sovereign nation states. In the next level are individual countries, each with a multi-sectored macro-economy. Various economic sectors (like industry and agriculture) exist in each country. Finally, each sector consists of different sub-sectors and projects. The conventional decision making process in a modern economy is shown on the right side of Figure A2.2. It 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, multi-sectoral 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 process (i.e., economic, financial and techno-engineering analyses). 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 A2.2 shows one convenient breakdown of environmental issues:

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

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

The causes of environmental degradation arise from human activity (ignoring natural disasters and other events of non-human origin), and therefore, we begin on the right side of the figure. The ecological effects of economic decisions must then be traced through to the left side. The techniques of environmental assessment (EA) have been developed to
facilitate this analysis (World Bank 1998). For example, destruction of a primary moist tropical forest may be caused by activities in many different sectors of the economy. Slash and burn agriculture often exacerbates forest depletion. Land clearing could be encouraged by land-tax incentives arising from fiscal policy. Hydroelectric dams will inundate large tracks of forest. The construction of rural roads may cause significant forest cutting. Mining in remote areas also could cause large-scale depletion of forests. Disentangling and prioritising these multiple causes (right side) and their impacts (left side) will involve a complex analysis.

Figure A2.2 also shows to bridge the ecology-economy interface, by mapping the EA results (measured in physical or ecological units) onto the framework of conventional economic analysis. A variety of environmental and economic techniques facilitate this process of incorporating environmental issues into traditional decision making. These include valuation of environmental impacts (at the local/project level), integrated resource management (at the sector/regional level), environmental macroeconomic analysis and environmental accounting (at the economy-wide level), and global/transnational environmental economic analysis (at the international level). Since there is considerable overlap among the analytical techniques described above, this conceptual categorisation should not be interpreted too rigidly. Furthermore, when economic valuation of environmental impacts is difficult, techniques such as multi-criteria analysis (MCA) would be useful (see Section A2.3).

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 co-ordinating policies in a large number of disparate and (usually) uncoordinated ministries and line institutions (i.e., energy, transport, agriculture, industry, finance, forestry, etc.).

Analogous reasoning may be readily applied to social assessment (SA) at the society-economy interface, in order to incorporate social considerations more effectively into the conventional economic decision making framework. In this case, the left side of Figure A2.2 would include key elements of SA, such as asset distribution, inclusion, cultural considerations, values and institutions. Impacts on human society (i.e., beliefs, values, knowledge and activities), and on the bio-geophysical environment (i.e., both living and non-living resources) are often inter-linked via second and higher order paths, requiring integrated application of SA and EA. For example, economic theory emphasises the importance of pricing policy to provide incentives that will influence rational consumer behaviour. However, cases of seemingly irrational or perverse behaviour abound, which might be better understood through findings in areas like behavioural and social psychology, and market research.

Such work has identified basic principles that help to influence society and modify human actions, including reciprocity (or repaying favours), behaving consistently, following the lead of others, responding to those we like, obeying legitimate authorities, and valuing scarce resources (Cialdini 2001). These insights reflect current thinking on the co-evolution of socio-economic and ecological systems.
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