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Sustainomics: A Trans-disciplinary Framework for Making Development More Sustainable

Mohan Munasinghe

Munasinghe Institute for Development (MIND), Colombo, Sri Lanka

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I. BASIC FRAMEWORK

Following the 1992 Earth Summit in Rio de Janeiro, and the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg, sustainable development has become well accepted worldwide. World decision makers are looking at this approach to address many critical policy issues.

The WCED (1987) defined it as “development which meets the needs of the present, without compromising the ability of future generations to meet their own needs”. Among many subsequent definitions, the sustainable development triangle in Figure 1(a) shows one widely-accepted concept proposed by Munasinghe, at the 1992 Earth Summit in Rio. It encompasses three major perspectives -- economic, social and environmental. Each viewpoint corresponds to a domain (and system) that has its own distinct driving forces and objectives. The economy is geared towards improving human welfare, primarily through increases in consumption of goods and services. The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social domain emphasizes enrichment of human relationships, achievement of individual and group aspirations, and strengthening of values and institutions.

Sustainomics was described as “a transdisciplinary, integrative, comprehensive, balanced, heuristic and practical meta-framework for making development more sustainable” (Munasinghe 1992). In Figure 1(b), the sustainomics framework and knowledge base support comprehensive and balanced assessment of trade-offs and synergies that might exist among the three dimensions of sustainable development. 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). Many disciplines contribute to the sustainomics framework, since sustainable development itself involves every aspect of human activity, including complex interactions among socioeconomic, ecological and physical systems.

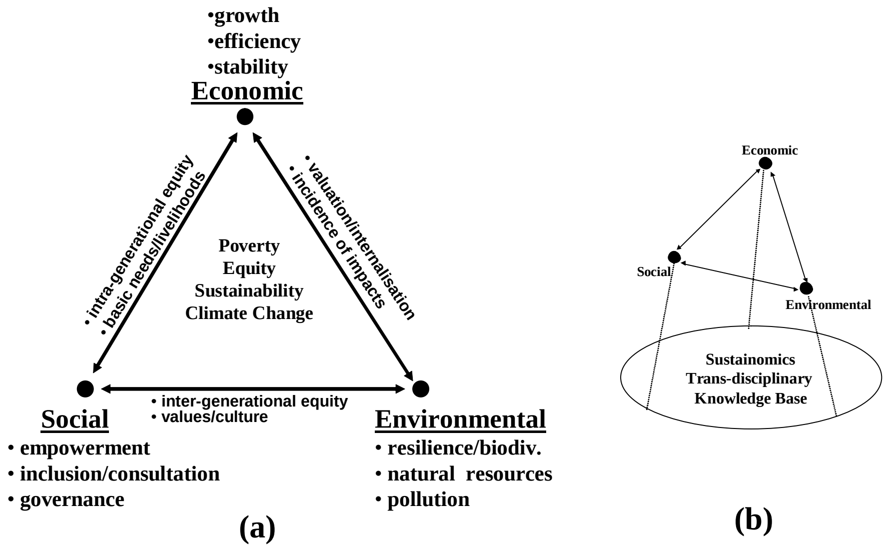


Figure 1 (a). Elements of sustainable development
1 (b). Sustainable development triangle supported by the sustainomics framework.
<u>Source</u>: adapted from Munasinghe [1992]

Historically, the development of the industrialized world focused on material production. Not surprisingly, most industrialized and developing nations have pursued the economic goal of increasing output and growth during the twentieth century. Thus, traditional development was strongly associated with economic growth, with important social dimensions as well (see the discussion on poverty and equity, below). By the early 1960s the lack of ‘trickle-down’ benefits to the growing numbers of poor in developing countries, resulted in greater efforts to improve income distribution directly. The development paradigm shifted towards equitable growth, where social (distributional) objectives, especially poverty alleviation, were recognized to be as important as economic efficiency. Protection of the environment has now become the third major pillar of sustainable development. By the early 1980s, a large body of evidence had accumulated that environmental degradation was a major barrier to development, and new proactive safeguards were introduced (such as the environmental assessments).

In the sustainomics framework, sustainable development is described as a process for improving the range of opportunities that will enable individual human beings and communities to achieve their aspirations and full potential over a sustained period of time, while maintaining the resilience of economic, social and environmental systems. Thus, sustainable development requires both increases in adaptive capacity and opportunities for improving economic, social and ecological systems. Improving adaptive capacity increases resilience and sustainability (Gunderson and Holling 2001). Expanding the set of opportunities for improvement gives rise to development. Heuristic behaviour of individual organisms and systems facilitates learning, the testing of new processes, adaptation, and improvement.

The precise definition and implementation of sustainable development remains an ideal, elusive (and perhaps unreachable) goal. Sustainomics proposes a less ambitious, but more focused and feasible strategy that merely seeks to ***'make development more sustainable'***. Such an incremental (or gradient-based) method is more practical, because many unsustainable activities are easier to recognise and eliminate. This approach seeks continuing improvements in the present quality of life at a lower intensity of resource use, thus leaving behind for future generations an undiminished stock of productive assets (i.e., manufactured, natural and social capital) that will improve their quality of life.

II. ELEMENTS OF SUSTAINABLE DEVELOPMENT

Economic Aspects

Economic progress is often evaluated in terms of welfare (or utility) – measured as willingness to pay for goods and services consumed. Thus, many economic policies typically seek to enhance income, and induce more efficient production and consumption of goods and services. The stability of prices and employment are among other important objectives.

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

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 (Hicks 1946). Economic efficiency continues to optimize both production and consumption. Problems arise in identifying the kinds of capital to be maintained (e.g., manufactured, natural, human and social capital), and their substitutability. Often, it is difficult to value these assets and the services they provide, particularly for ecological and social resources. Even key economic assets may be overlooked, especially in situations where non-market based transactions are important. Meanwhile, the equation of welfare with monetary income and consumption has been challenged for many years. More recently, Maslow (1970) and others have identified hierarchies of needs that provide psychic satisfaction, beyond mere goods and services.

The issues of uncertainty, irreversibility and catastrophic collapse pose additional difficulties, in determining dynamically efficient development paths. Many common microeconomic approaches rely on marginal analysis (e.g., comparing incremental costs and benefits of economic activities), which assumes smoothly changing variables. They are inappropriate for analysing large changes, discontinuous phenomena, and sudden transitions among multiple equilibria. Recent work has begun to explore the behaviour of large, non-linear, dynamic and chaotic systems, and concepts like system vulnerability and resilience.

Environmental Aspects

Development in the environmental sense is a recent concern relating to the need to manage scarce natural resources in a prudent manner – because human welfare ultimately depends on ecological services. Ignoring safe ecological limits could undermine long-run prospects for development. Recent literature covers links among environment, growth and sustainable development (Faucheux et al. 1996, Munasinghe et al. 2001).

Environmental sustainability focuses on overall viability and normal functioning of natural systems. For ecological systems, sustainability is defined by a comprehensive, multiscale, dynamic, hierarchical measure of resilience, vigour and organization. Resilience is the ability of ecosystems to persist despite external shocks, i.e., the amount of disruption that will cause an ecosystem to switch from one system state to another (Holling 1973). An ecosystem state is defined by its internal structure and set of mutually re-inforcing processes. Vigour is associated with the primary productivity or growth of an ecosystem. Organization depends on both complexity and structure of the system. For example, a multicellular organism like a human being is more highly organized than a single celled amoeba. Higher states of organization imply lower levels of entropy. Thus, the second law of thermodynamics requires that sustainability of complex organisms and systems depend on the use of low entropy energy derived from their environment, which is returned as (less useful) high entropy energy.

In this context, natural resource degradation, pollution and loss of biodiversity are detrimental because they increase vulnerability, undermine system health, and reduce resilience. The notions of a safe threshold and carrying capacity are important, to avoid catastrophic ecosystem collapse. It is useful to also think of sustainability in terms of the normal functioning and longevity of a nested hierarchy of ecological and socioeconomic systems, ordered according to scale – e.g., a human community would consist of many individuals, who are themselves composed of a large number of discrete cells. Gunderson and Holling (2001) use the term ‘panarchy’ to denote such a hierarchy of systems and their adaptive cycles across scales. A system at a given level is able to operate in its stable (sustainable) mode, because it is protected by slower and more conservative changes in the super-system above it, while being simultaneously invigorated and energized by faster changes taking place in sub-systems below it.

Sustainable development is not necessarily synonymous with maintaining the ecological *status quo*. A coupled ecological-socioeconomic system could evolve, while maintaining levels of biodiversity that guarantee resilience of ecosystems on which future human consumption and production depend.

Social Aspects

Social development usually refers to improvements in both individual well-being and overall social welfare resulting from increases in social capital – typically, the accumulation of capacity enabling individuals and communities to work together. The institutional component of social capital involves formal laws as well as traditional or informal understandings that govern behaviour, while the organizational component is embodied in individuals and communities operating within these institutional arrangements (North 1990). The quantity and quality of social interactions underlying human existence (including levels of mutual trust and shared social norms), determine the stock of social capital. Thus, social capital grows with greater use and erodes through disuse, unlike economic and environmental capital, which are depreciated or depleted by use. Furthermore, some forms of social capital may be harmful (e.g., cooperation within criminal gangs).

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

Social sustainability parallels environmental sustainability. Reducing vulnerability and maintaining the the ability of socio-cultural systems to withstand shocks, is also important. Enhancing human capital (through education) and strengthening social values, institutions, and governance are key aspects. Many harmful changes occur slowly, and their long term effects are often overlooked in socio-economic analysis. Preserving cultural capital and diversity worldwide, strengthening social cohesion, and reducing destructive conflicts, are integral elements of this approach. An important aspect involves empowerment and broader participation through subsidiarity – i.e., decentralization of decision making to the lowest (or most local) level at which it is still effective. In summary, for both ecological and socioeconomic systems, the emphasis is on improving system health and its dynamic ability to adapt to change across a range of spatial and temporal scales, rather than the conservation of some ‘ideal’ static state.

Poverty and Equity

Poverty and equity are two important issues, which have social, economic and environmental dimensions – see Figure 1(a). Over 2.8 billion people (almost half the global population) live on less than US$2 per day, and 1.2 billion barely survive on under US$1 per day. The top 20 percentile of the world’s population consumes about 83 percent of total output, while the bottom 20 percentile consumes only 1.4 percent. Income disparities are worsening – the per capita ratio between the richest and the poorest 20 percentile groups was 30 to 1 in 1960 and over 80 to 1 by 1995.

Equity is an ethical and usually people-oriented concept with primarily social, and some economic and environmental dimensions. It focuses on the basic fairness of both decisionmaking processes and outcomes. Equity may be assessed in terms of several generic approaches, including parity, proportionality, priority, utilitarianism, and Rawlsian distributive justice (Rawls 1971). Societies normally seek to achieve equity by balancing and combining several of these criteria.

Poverty alleviation, improved income distribution and intra-generational (or spatial) equity are key aspects of economic policies seeking to increase overall human welfare. Broadly speaking, economic efficiency provides guidance on producing and consuming goods and services more efficiently, but is unable to provide a means of choosing (from a social perspective) among alternative patterns of consumption which are efficient. Equity principles provide better tools for making judgements about such choices.

Social equity is also linked to sustainability, because grossly unfair distributions of income and social benefits are unlikely to be lasting in the long run. Equity will be strengthened by enhancing pluralism and grass-roots participation in decisionmaking, and by empowering disadvantaged groups. In the long term, inter-generational equity is vital, where both equity and efficiency aspects are affected by the economic discount rate. The sustainomics framework outlines methods of reconciling potential conflicts between equity and economic efficiency.

Equity in the environmental sense has received recent attention because of disproportionately greater environmental damages suffered by poor groups. Thus, poverty alleviation efforts are being broadened (beyond raising monetary incomes), to address the degraded environmental and social conditions facing the poor.

In summary, both equity and poverty have economic, as well as social and environmental dimensions, and therefore, they need to be assessed using a comprehensive set of indicators. Economic policies should emphasise expanding employment and gainful opportunities for poor people through growth, improving access to markets, and increasing both assets and education. Social policies need to focus on empowerment and inclusion, by making institutions more responsive to the poor and removing barriers that exclude disadvantaged groups. Environmental measures to help poor people might seek to reduce their vulnerability to disasters, crop failures, loss of employment, sickness, economic shocks, etc. Thus, an important objective of poverty alleviation is to provide poor people with assets (e.g., social, natural and economic), that will reduce their vulnerability, and increase the capacity for both short-run coping and longer-run adaptation to external shocks. The foregoing ideas blend with the sustainable livelihoods approach, which focuses on access to portfolios of assets, capacity to withstand shocks, gainful employment, and social processes.

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

Consistent integration of economic, social and environmental considerations

We begin by comparing the concepts of ecological, social and economic sustainability. Maintaining the set of opportunities is as important as the preservation of the asset base. The preservation of biodiversity maintains options and allows the system to retain resilience by protecting it from external shocks, in the same manner that preservation of the capital stock protects economic assets for future consumption. Differences emerge because under the economic definition, a society that consumes its fixed capital without replacement is not sustainable, whereas using an ecological approach, loss of resilience implies a reduction in the self-organization of the system, but not necessarily a loss in productivity. In the case of social systems, resilience depends on the capacity of human societies to adapt and continue functioning in the face of stress and shocks. Thus, linkages between socio-cultural and ecological sustainability emerge through the organizational similarities between human societies and ecological systems, and the parallels between biodiversity and cultural diversity. In the longer term, the concept of co-evolution of social, economic and ecological systems within a larger, more complex adaptive system, provides useful insights regarding harmonious integration of the various elements of sustainable development – see Figure 1(a).

It is important to integrate and reconcile the economic, social and environmental aspects within a holistic and balanced sustainable development framework (see recent issues of *Ecological Economics* and *Conservation Ecology)*. Two broad approaches, based on the concepts of *optimality* and *durability*, are relevant for this purpose.

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. 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: $\mathrm{Max}\int_0^\infty W(C, Z).e^{-rt}\ dt$. Here, W is a function of C (consumption), and Z (set of other relevant variables), while r is the discount rate. Side constraints may be imposed to satisfy sustainability needs – e.g., non-decreasing stocks of productive assets.

Some ecological models also optimize variables related to system vigour, like energy use, nutrient flow, or biomass production. In economic models, utility is often measured in terms of net benefits of economic activities. More sophisticated economic optimization approaches 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 by ensuring non-decreasing stocks of assets.

Some analysts support a ‘strong sustainability’ constraint, which requires separate preservation of each category of critical asset (e.g., manufactured, natural, socio-cultural and human capital), assuming that they are complements rather than substitutes. 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 various asset types are substitutes and may be valued.

Side constraints are often necessary, because the optimization approach (including economic efficiency and valuation) may not be easily applied to ecological objectives like protecting biodiversity and improving resilience, or to social goals such as promoting equity and empowerment. Such environmental and social variables cannot be easily incorporated within a single valued objective function based on cost-benefit analysis. Thus, techniques like multi-criteria analysis may be required, to facilitate trade-offs among non-commensurable variables. Moreover, the lagged price system might not anticipate irreversible environmental and social harm, and non-linear system responses that could lead to catastrophic collapse. Therefore, non-economic indicators of environmental and social status are helpful. The constraints on critical environmental and social indicators are proxies representing safe thresholds, which help to maintain the viability of those systems. Risk and uncertainty also necessitate the use of decision analysis tools.

Durability

The second broad integrative approach focuses 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 (i.e., risk aversion), in order to stay within critical environmental, social and technical limits (see the discussion on the precautionary principle).

Economic system durability might require consumption levels to be maintained – 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 monitor the durability or normal functioning of complex ecological, social and techno-economic systems. There is the likelihood of further interaction here due to linkages between the sustainability of social, ecological and techno-economic systems – e.g., social disruption and conflict could exacerbate damage to both ecological and techno-economic systems, and *vice versa*. In fact, long-standing social norms in many traditional societies have helped to protect the environment.

Durability encourages a holistic systemic viewpoint, which is important in sustainomics analysis. The self-organizing and internal structure of complex systems often make ‘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. 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. 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 futures (rather than one optimal result). This approach parallels research on integrating human actors into ecological models, including multiple-agent modeling to account for heterogeneous behaviour, bounded rationality leading to different perceptions and biases, and social interactions involving imitation, reciprocity and comparison.

In the durability approach, maintaining asset stocks enhances system sustainability, because various forms of capital are a bulwark that decreases vulnerability to external shocks and reduces irreversible harm, rather than merely producing more economic outputs. System vulnerability, 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 – e.g., vulnerability and risk of failure in the case of an electric power system, depend on the traditional reserve margin (supply minus demand), as well as the probability of breakdown of key system components or stochastic surges in demand.

Indicators

Since asset stocks are important to both the optimal and durable approaches, the practical implementation of sustainomics principles will require the identification of relevant economic, social and environmental indicators, at different levels of aggregation ranging from the global/macro to local/micro. Indicators must be comprehensive in scope, multi-dimensional in nature (where appropriate), and account for spatial differences. A wide variety of indicators are described in OECD (1994), Munasinghe and Shearer (1995), UN (1996), UNDP (1998), World Bank (1998), and Commission on Sustainable Development (1998).

Measuring economic, environmental, human and social capital also raises various problems. Manufactured capital may be estimated using conventional neoclassical economic analysis. Market prices are useful when economic distortions are relatively low, while shadow prices could be applied in cases where market prices are unreliable. 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 this physical damage could be valued using environmental and resource economics techniques. Human resource stocks are often measured by educational levels, productivity and earning potential. Social capital is more difficult to assess. Putnam (1993) described it as ‘horizontal associations’ among people, or social networks and associated behavioural norms and values, which affect the productivity of communities. Social capital may be viewed more broadly in terms of social structures, which facilitate the activities of agents in society – including both horizontal and vertical associations (like firms). An even wider definition is implied by the institutional approach that includes not only the mainly informal relationships implied by the earlier two views, but also more formal frameworks provided by governments, political systems, and legal provisions. 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).

Complementarity and convergence of optimal and durable approaches

The two approaches are often complementary in national economic management. For example, economywide policies involving both fiscal and monetary measures (e.g., taxes, subsidies, interest and foreign exchange rates) might be optimized using quantitative macroeconomic models. Nevertheless, decision makers inevitably modify these economically 'optimal' policies before implementing them, to take into account other 'durable' sociopolitical considerations (like poverty alleviation, regional factors, etc.), which facilitate governance and stability. The determination of an appropriate target trajectory for future global GHG emissions provides another useful illustration of the interplay of durability and optimality. Climate change researchers are currently exploring the application of large and complex integrated assessment models that include coupled sub-models representing various ecological, geophysical and socioeconomic systems -- with scope to test both optimality and durability approaches.

In practice, the two approaches point towards convergent solutions. First, wastes ought to be generated at rates within the assimilative capacity of the environment. Second, scarce renewable resources should be utilized at rates compatible with the natural rate of regeneration. Third, non-renewable resource use rates should depend on the substitutability between these resources and technological progress. Both wastes and natural resource inputs might be minimized, by moving from linear throughput to closed loop (or recycling) mode. Finally, inter- and intra-generational equity (especially poverty alleviation), pluralistic and consultative decision making, and enhanced social values and institutions, are important additional aspects.

Tools for SD Analysis and Assessment

Some important tools for SD analysis and assessment include: the Action Impact Matrix (AIM) for prioritising the economic, environmental and social interactions of various macroeconomic and sectoral development policies; advanced cost-benefit analysis (CBA) including economic valuation of environmental and social impacts; and multi-criteria analysis (MCA), especially in cases where some impacts cannot be easily quantified in monetary terms.

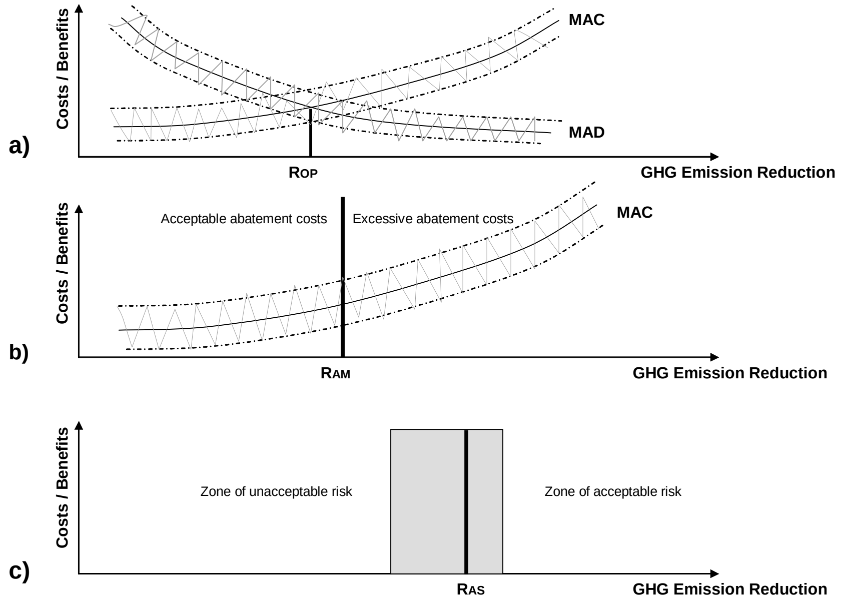
Sustainable Development Assessment (SDA) is another important tool to ensure balanced analysis of both development and sustainability concerns in both policies and projects. The 'economic' component of SDA is based on conventional economic and financial analysis (including cost benefit analysis). The other two key components are environmental and social assessment (EA and SA). SDA also includes poverty assessment. Thus, SDA seeks to integrate and harmonise economic, environmental and social analyses.

IV. APPLYING THE SUSTAINOMICS FRAMEWORK

Global scale: using optimality and durability to determine desirable GHG emission levels.

To determine target GHG emission levels using an economic optimizing framework, the ideal solution would be first to estimate the long-run marginal abatement costs (MAC) and the marginal avoided damages (MAD) associated with different GHG emission profiles – see Figure 2(a). The optimal emission levels would be determined at the point where future benefits (in terms of climate change damage avoided by reducing one unit of GHG emissions) are just equal to the corresponding costs (of mitigation measures required to reduce that unit of GHG emissions), i.e., MAC = MAD at point R_{OP}.

Fig. 2 Determining mitigation targets: (a) cost-benefit optimum, (b) affordable safe minimum standard, (c) absolute standard. Error bars indicate data uncertainty. Adapted from IPCC (1996).



Durable strategies become more relevant when we recognize that MAC and/or MAD might be poorly quantified and uncertain. Figure 2(b) assumes that MAC is better defined than MAD. First, MAC is determined using techno-economic least cost analysis – an optimizing approach. Next, the target emissions are set on the basis of the affordable safe minimum standard (at R_{AM}), which is the upper limit on costs that will still avoid unacceptable socioeconomic disruption – this is closer to the durability approach.

Finally, Figure 2(c) indicates an even more uncertain world, where neither MAC nor MAD is defined. Here, the emission target is established on the basis of an absolute standard (R_{AS}) or safe limit, which would avoid an unacceptably high risk of damage to ecological (and/or social) systems. This last approach would be more in line with the durability concept.

National-economywide scale: using the action impact matrix (AIM) for macro-policy analysis

National policy makers routinely make 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 (Munasinghe and Cruz 1994). At this 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, via useful new indicators and measures such as the system of environmentally adjusted environmental accounts (SEEA), green gross national product (GNP), and genuine savings. In this context, the Action Impact Matrix (AIM) approach is a sustainomics tool that helps to identify and analyse economic-environmental-social interactions, and formulate effective sustainable development policies.

Table I shows a simplified AIM, although an actual one would be larger and more detailed. The AIM helps to promote an integrated view, meshing development decisions with priority economic, environmental and social impacts. The leftmost column lists examples of key development interventions (both policies and projects), while the top row indicates some typical sustainable development impacts/issues. Thus the elements or cells in the matrix help to:

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

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

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 impacts. Thus, the preliminary AIM helps prioritize the most important links between policies and their sustainability impacts.

One typical primary energy policy shown in row 3 involves increasing energy prices closer to marginal costs – to improve energy efficiency, while decreasing air pollution and GHG emissions. A complementary environmental policy measure indicated in column 4 consists of adding pollution taxes to marginal energy costs, which will further reduce air pollution and GHG emissions. Increasing public sector accountability constitutes another complementary policy that will reinforce favourable responses to these price incentives, by reducing the ability of inefficient firms to pass on cost increases to consumers or to transfer their losses to the government.

Next, a major hydroelectric project is shown lower down in the Table as having two adverse impacts (inundation of forested areas and village dwellings), as well as one positive impact (the replacement of thermal power generation, thereby reducing air pollution and GHG emissions). A re-afforestation project coupled with resettlement schemes helps address the negative impacts.

This matrix-based approach therefore encourages the systematic articulation and coordination of policies and projects to make development more sustainable.

Table 1. A Simplified Preliminary Action Impact Matrix[1].

ACTIVITY/POLICY	MAIN OBJECTIVE	IMPACTS ON KEY SUSTAINABLE DEVELOPMENT ISSUES			
		Land Degradation	*Air Pollution*	*Resettlement*	*Others*
Macro-economic & Sectoral Policies	Macroeconomic and sectoral improvements	Positive impacts due to removal of distortions Negative impacts mainly due to remaining constraints			
· *Exchange Rate*	· Improve trade balance and economic growth	(-H) (deforest open-access areas)			
· *Energy Pricing*	· Improve economic and energy use efficiency		(+M) (energy efficiency)		
· *Others*					
Complementary Measures	Specific/local social and environmental gains	Enhance positive impacts and mitigate negative impacts (above) of Broader macroeconomic and sectoral policies			
· *Market Based*	· Reverse negative impacts of market failures, policy distortions and institutional constraints		(+M) (pollution tax)		
· *Non-Market Based*		(+H) (property rights)	(+M) (public sector accountability)		
Investment Projects	Improve efficiency of investments	Investment decisions made more consistent with broader policy and institutional framework			
· Project 1 *(Hydro Dam)*	· Use of project Evaluation (cost benefit analysis, Environmental Assessment, Multi-criteria Analysis, etc.)	(-H) (inundate forests)	(+M) (displace fossil fuel use)	(-M) (displace people)	
· Project 2 *(Re-afforest and relocate)*		(+H) (replant forests)		(+M) (relocate people)	

Source: Munasinghe (1992)

Notes

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

Analysis and remediation:

This process may be developed further to assist in *analysis* and *remediation*. For example, more detailed analyses and modelling may be carried out for those matrix elements in the preliminary AIM that had been already identified as representing high priority linkages between economywide policies and economic, environmental and social impacts. Such analyses, which would depend on planning goals and available data and resources, may range from fairly simple methods to rather sophisticated economic, ecological and social models, included in the sustainomics toolkit. This process leads 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.

Local-project scale: Multicriteria analysis of small hydropower projects

Well accepted environmental and social assessment procedures at the project/local level may be readily adapted to assess environmental and social effects of micro-level activities. When monetary valuation of environmental and social effects is not feasible, MCA may be used. Here, we summarise how Morimoto, Munasinghe and Meier (2000) have used multi-criteria analysis (MCA) to compare hydroelectric power schemes. The three main sustainable development issues considered are 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 growing power demand in Sri Lanka. Assume that the benefits from each additional kWh are the same, the analysis seeks to minimize 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 monetary-valued CBA framework.

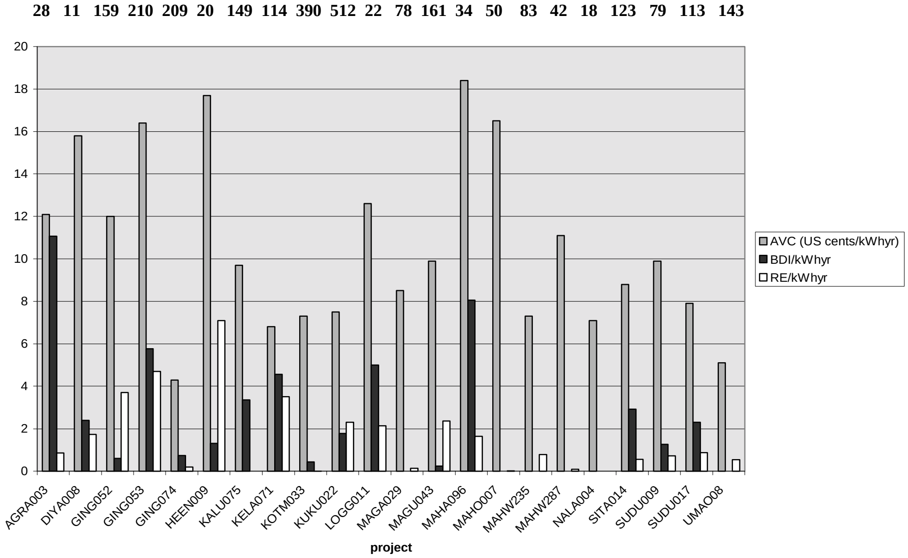
Environmental, social and economic indicators:

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

Although dam sites are less densely populated, resettlement is still a problem. Generally, 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. Living standards often become worse and several problems could arise, like malnutrition, erosion of community cohesion and psychological distress due to changed living conditions. Hence, minimising the number of people resettled due to dam construction is an important social objective.

The critical economic indicator – average cost per kWh per year – may be estimated from project costs at each site. The annual energy generation potential at various sites ranges from about 11 to 210 KWh (Figure 3). All three variables (biodiversity index, number of people resettled, and generation costs), are weighted by the inverse of the amount of electrical energy generated. This scaling removes the influence of project size and makes them more comparable.

Figure 3. Average generation costs (AVC), biodiversity index (BDI), and number of resettled people (RE) by hydroelectric project. All indices are per kWh per year. Numbers of people resettled and the biodiversity index are scaled for convenience (by the multipliers 10^{-5} and 10^{-9} respectively). The values at the top of the graph indicate the annual energy generation in gigawatt hours (GWh).



Source: Morimoto, Munasinghe and Meier (2000)

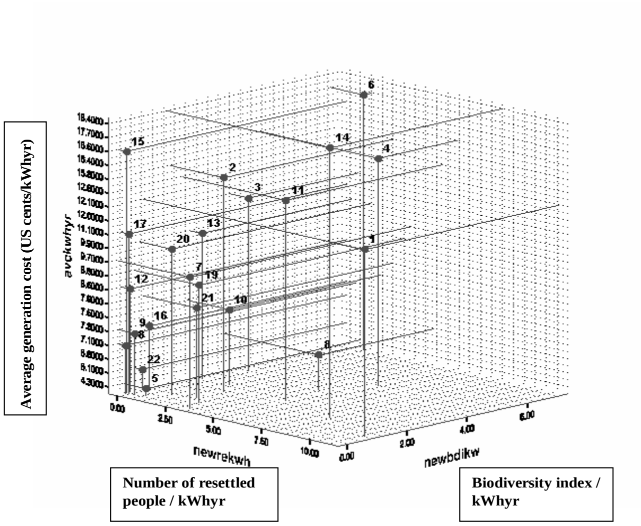
Basic Results:

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

Figure 3 shows that on a per kWh per year basis, the project named AGRA003 has the highest biodiversity index, HEEN009 has the highest number of resettled people, and MAHA096 has the highest average generation cost. Further important comparisons may be made. For example, KALU075 is a relatively large project where 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 among other projects.

Figure 4 provides a three-dimensional analysis of sustainable development indicators for these hydropower sites, where the respective axes represent economic, ecological, and social objectives. The closer to the origin any given project lies, the better it is in terms of achieving these three objectives. This type of analysis gives policymakers some idea about which project is more favorable from a sustainable energy development perspective.

Figure 4. Three dimensional MCA of sustainable development indicators for various hydropower options.
Source: Morimoto, Munasinghe and Meier [2000]



Suppose we arbitrarily give all three objectives an equal weight. Then, each project may be ranked according to its absolute distance from the origin. Thus, the best project lies closest to the origin. On this overall basis, from a sustainable energy development perspective, the most favorable project is GING074 (point 5), whereas the least favorable one is MAHA096 (point 14).

Conclusions:

Simple graphical presentations help policy-makers compare project alternatives by clearly identifying their sustainable development characteristics. The multi-dimensional analysis supplements more conventional CBA (based on economic analysis alone). Since each project has different features, assessing them by looking at only one aspect 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 attributes are minor. In reality, there may be several additional variables which could describe the economic, social and environmental aspects of sustainable development. Including other attributes might provide new insights. A second extension of this study is to include other renewable sources of energy in the analysis. Finally, more sophisticated 3D-graphic techniques may yield better and clearer representations.

A more detailed version of this paper may be found in:
Munasinghe, M. (2002) 'The sustainomics trans-disciplinary meta-framework for making development more sustainable: applications to energy issues', *International Journal of Sustainable Development*, Vol. 4, No.2, pp.6-54.

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