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Sustainable Energy Development (SED): Issues and Policy

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1 Energy, Environment and the Economy: The Nexus

The state of the environment is a major worldwide concern today. Pollution in particular is perceived as a serious threat in the industrialized countries, where quality of life had hitherto been measured mainly in terms of growth in material output. Meanwhile, environmental degradation has become a serious impediment to economic development and the alleviation of poverty in the developing world. The growing evidence of environmental problems is due to a combination of factors. Over the last three decades the environmental impact of human activities has grown considerably due to the increase in economic activity, population and per capita consumption.

Among the human activities that cause changes in the environment, those associated with the energy sector have great impact. Energy production, conversion, transportation and utilization have been and continue to be a primary source of local, transnational and global pollution. The environmental effects of energy are: groundwater and air contamination; land degradation and changes in use; marine and coastal pollution; ecosystems destruction and loss of biodiversity; damage to health, synethic structures and natural systems from SO_2 and NO_x and ash particulates which degrade air quality; and finally, greenhouse gas emissions which may have long-term implications for the global environment.

Despite such problems, however, energy services such as heating, refrigeration, cooking, lighting, communications, motive power and electricity are essential for economic growth and human well-being. Economic growth prior to the 1970s was always accompanied by a corresponding global increase of demand for energy. As a direct consequence of the oil price increases, decoupling between economic growth and energy demand growth was achieved in the mature economies of industrialized countries (ICs) which were able to reduce energy wastage relatively easily and also achieve a better energy management by restructuring and through energy efficient technologies. Such decoupling was not observed in developing countries (DCs). As DCs are still in the early stages of economic development and have higher growth rates, there is a much closer linkage between economic growth and energy consumption than in industrialized countries (Munasinghe 1991).

Current Status

At present developing countries comprise 77 percent of the world's population but utilize only a quarter of the world's energy. A majority of this population have little or no access to any form of commercial energy. A large proportion of the DCs population live in rural areas and continue to rely heavily on traditional biomass fuels such as wood, crop waste and animal dung. OECD countries, in contrast, consumed over half the world's energy and nearly six times more energy per person than did developing and CEE/CIS countries. However, energy demand has been growing rapidly in the developing countries in the past fewdecades (Table 1). In the last decade alone, the rate of growth of DC energy consumption has been about six times that of the OECD countries and twice the average world growth rate.

The rapid growth in energy demand in DCs (driven primarily by economic expansion, population growth, urbanization, the increasing penetration of energy-using products, and the transition from traditional energy sources to commercial sources) has surpassed the growth in energy production and power generation capacities, thus creating shortages in primary fuels and electricity. To meet this rising energy demand, DCs require tremendous financial resources. In addition to the economic burden, environmental degradation associated with an expanding energy sector compound the energy-related problems in DCs.

The crucial dilemma for the developing world is how to reconcile development goals and the elimination of poverty, which will require increased use of energy and raw materials, with responsible stewardship of the environment. This has to be done without overburdening their already weak economies. Hence, the challenge facing DCs today is meeting the rising energy demand in a manner that will not absorb inordinate amounts of investment, which in turn would divert funds from other worthy development goals, such as poverty alleviation and the provision of education and health care.

Future Economic Growth and Energy Needs

The world economy is expected to continue to grow at a healthy rate over the next few decades. The World Bank estimates the GNP of large industrialized countries (ICs) to grow at an average rate of 2.7 percent annually over the 1994-2003 period and that of DCs to grow at 4.8 percent annually over the same period with above average growth in East and South Asia (7.6 percent and 5.3 percent respectively). The prospects for economic growth in DCs prompting a similar increase in energy demand are obvious.

The world's population is expected to grow by 3 billion during the period 1990-2020, with ninety percent of the increase taking place in DCs. Only eight countries are expected to account for half of global population growth, and a significant portion of global energy demand growth, over the next 30 years: India, China, Pakistan, Bangladesh, Brazil, Indonesia, Mexico, and Vietnam (WDR 1992 and WEC 1993). According to the WEC "high-growth" case, world primary energy consumption is estimated to double to roughly 17.2 Mtoe

Table 1

Average Annual Growth Rates of Energy Demand and GDP

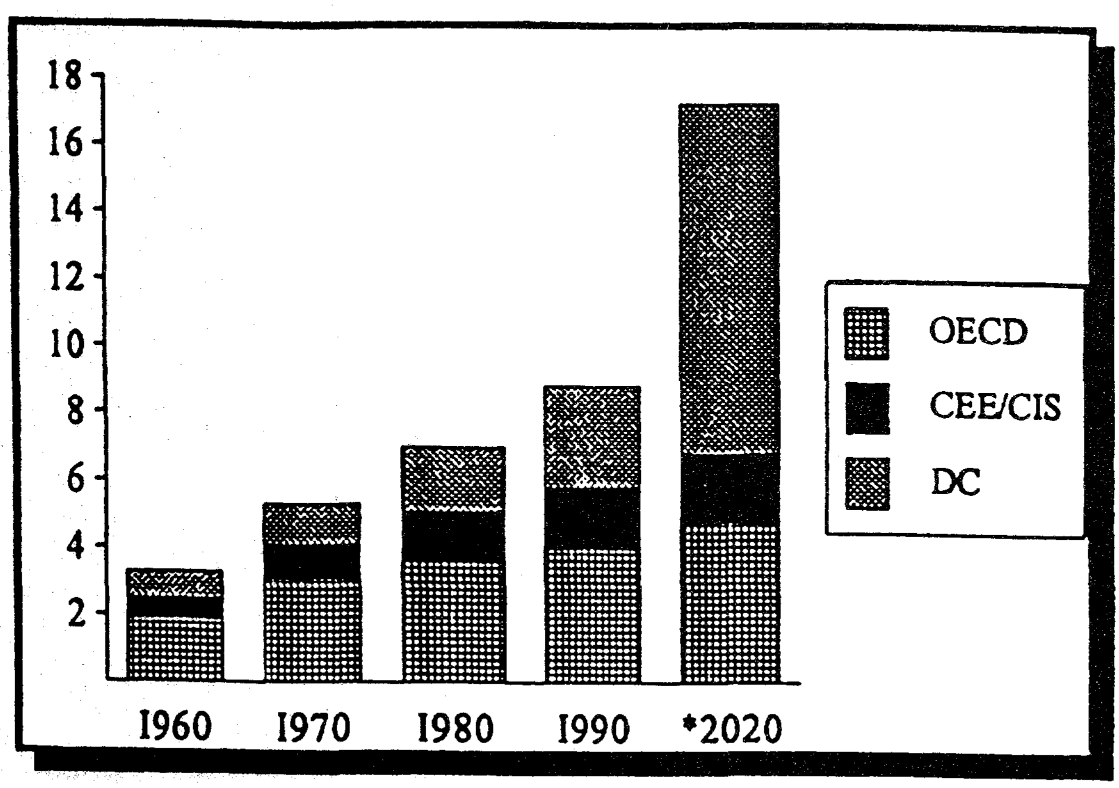
	Energy Demand				Economic Growth			
Year	OECD	DCs	C&EEs	World	OECD	DCs	C&EEs	World
1961-70	5.0	4.1	5.2	4.8	4.7	4.7	5.2	1.7
1971-80	1.8	4.7	3.4	3.0	3.2	4.8	3.4	1.5
1981-90	0.8	4.7	2.2	2.3	2.9	5.6	1.3	3.8

Sources: WEC 1992.
Khatib & Munasinghe 1992.

(megatons of oil equivalent) in the next 30 years, with almost 90 percent of the growth coming from the DCs (see Figure 1). Under this scenario, the share of total energy consumption accounted for by the OECD will have fallen from over 50 percent in 1990 to under 30 percent by 2020, while the share of DCs will almost double to 60 percent during the same period.The International Energy Agency (IEA) has forecast that through the year 2010, world energy use will grow at an annual rate of 2.1 percent, with East Asian countries energy use growing at more than 4 percent (World Energy Outlook, OECD, 1994).

Figure 1

Past and Future Energy Demand (Mtoe)



Source: World Energy Council 1992.

2 Key Role of the Electricity Sector

Electricity is clean, versatile, easily accessible and simple to distribute. It is also essential to maintain a reasonable quality of life, and for sustainable development. Due to this phenomenon, electricity is gaining a larger share of energy in final use and the demand for it is increasing worldwide at almost twice the rate of demand for primary energy. Currently, the worldwide electricity demand is increasing at a rate of over 3.6 percent annually, which is slightly higher than the world's economic growth rate, twice the population growth rate and more than 1.5 times that of global commercial energy consumption. Presently fuels for electricity production are claiming 36 percent of total energy demand and in the next thirty to forty years, more than half the world's primary commercial energy sources would be utilized in electricity production.

Electricity has not only transformed the quality of life and work, but also created one of the largest industries, with worldwide revenues estimated at more than $800 billion in 1992 (Flavin and Lenssen 1993). Thus, in addition to its widely recognized role as a catalyst to economic activity in other sectors, the electricity sector itself makes a direct and significant contribution to the economy.

Despite a general recognition of the indispensable nature of electricity, one third of the world's population is still deprived of access to electricity, mostly in developing countries. The ICs are the most electricity intensive, containing 16 percent of the world population and consuming almost 60 percent of the globe's electricity. On average, developing countries use only 500 KWh of electricity per capita per year compared with more than 5000 KWh in Europe and more than 10,000 KWh in the USA (World Bank 1992).

Table 2

Electricity Demand And Its Share In Total Primary Energy

	1990 (actual)		2000			2020		
	TWH	% of energy	TWH	% of energy	growth%	TWH	% of energy	growth %
OECD	6800	41	8600	-	2.40	10900	49.0	1.2
DCs	2630	30	5050	-	6.75	12000	47.3	4.5
C&EEs	2270	34	2850	-	2.30	3700	50.0	1.2
World	11700	36	16500	-	3.20	26600	48.3	2.4

Source: Khatib and Munasinghe 1992.

Electricity and the Developing World

Of the various forms of energy, electricity is particularly important in the context of the developing world. The provision of electricity greatly enhances the quality of life in DCs particularly for the poor. It improves health standards, and assists in education and in motivating people. Rural electrification (RE) also helps to retard migration from rural areas to cities and enhances opportunities for income generation and employment in rural areas. To the extent that it displaces less efficient and more environmentally damaging fuels, electricity is essential for sustainable development. Hence, given the vital role electricity plays in the development process, the future prospects for economic growth are closely linked to the provision of adequate and reliable electricity supplies. Electricity demand in DCs grew very rapidly over the past three decades with consumption increasing over thirteen fold since 1960. During this period electricity consumption has grown at a rate which is over 1.5 times the rate of energy consumption and economic growth (Table 3).

A direct relationship between electricity and economic growth cannot be deduced as easily as in the case of total energy. This is mainly because electricity growth depends not only on economic growth, but also on the substitution of electricity for other commercial and non-commercial energy. Such a substitution depends on the cost and productivity of electricity use compared to other commercial fuels, and also on the changes in quality and style of life. In the more developed OECD countries, such substitution decreases as more energy uses are shifted into electricity use, moving the share of electricity in final energy to saturation.

Table 3

Growth Trends in Electricity, Energy and Economy

	Electricity growth			Electricity/GDP		
Year	OECD	DC	World	OECD	DC	World
1961-70	5	4.1	4.8	1.6	2	4.7
1971-80	1.8	4.7	3	1.3	2	3.5
1981-90	0.8	4.7	2.3	0.9	2.2	2.7
1991-2020	0.7	4.2	2.2	0.7	0.9	0.7

	Energy/GDP			Electricity/Energy		
Year	OECD	DC	World	OECD	DC	World
1961-70	1.1	0.9	2.8	1.5	2.3	1.7
1971-80	0.6	1	0.5	2.4	2	1.8
1981-90	0.3	1.3	0.6	3.1	1.8	1.5
1991-2020	0.3	0.8	1.7	2.3	1.2	1.2

Source: Munasinghe 1991.
WEC 1992.

Table 3 shows an interesting contrast between electricity demand and economic growth in OECD countries and DCs. Owing to the decoupling of economic growth from energy demand in the 1970s, the ratio of electricity growth to economic growth in OECD countries steadily declined. Developing countries which still have a long way to go in satisfying their basic electricity needs showed a very high electricity/economy growth relationship in the past three decades. While it is evident that there is a trend in OECD countries to decouple economic growth from dependence on increased electricity consumption, in developing countries the electricity/economy ratio will remain relatively high. Developing countries will require more electricity in the future and this growth in demand is influenced by the electricity share in their economies and energy demand, as well as by their economic growth. Table 4 outlines this relationship. From the table it is clear that the growing share of electricity fuels in total energy is increasing, but at a declining rate. This growth will continue until electricity reaches a point beyond which it cannot fully replace other fuels (Khatib and Munasinghe 1992).

Given the benefits of electricity and its importance to the developing world, the demand for electricity can only grow. In the medium-term, assuming no drastic changes in the past trends with respect to demand management and conservation, the World Bank estimates that the demand for electricity in DCs will grow at an average annual rate of 6.7 percent in the 1990s (Table 2). This compares with actual growth rates of 10 percent and 8 percent in the 1970s and 1980s respectively. Such rates of growth indicate the need for large additions in capacity. The Asia Regions requirements dominate with almost two-thirds of the total, and coal and hydro are the primary sources— both which have specific environmental problems associated with their use (Munasinghe 1992).

Power Sector Problems and Investment Needs in DCs

Currently industrial and residential electricity demand in DCs have exceeded their power generating capacities, resulting in frequent power shortages and blackouts. Power shortages in any country affect it in two ways: they handicap productive activities and delay social development. On the output side, electricity shortages disrupt production. For India the cost of power shortages to the industrial sector has been estimated at 1.5 percent of GDP and in Pakistan at 1.8 percent (Khatib and Munasinghe 1992). Power shortages also discourage inves-

Table 4

Electricity Fuels Share in Total Primary Energy (%)

Year	OECD	C & EE	DCs	World
1970	32	27	18	29
1980	38	32	25	34
1990	41	34	31	36

Source: Khatib and Munasinghe 1992.

tors by affecting production and requiring more investment for on-site electricity production or standby supplies. This not only requires more investment by entrepreneurs in DCs where capital is already limited, but it also distracts investors from their main productive activity. It would (for small investors) increase the cost of operation, since electricity from small private generation is more expensive than public national supplies (Munasinghe 1990b).

Structural, institutional and financial problems further exacerbate the already inadequate electricity supply in DCs. Poor operating performances, poor maintenance of plants, technical and non-technical transmission and distribution system losses and high fuel consumption have resulted in high energy wastage and economic losses. Poor maintenance practices account for some of the low availability of power generating capacity, which averages less than 60 percent for thermal plants in DCs, compared with more than 80 percent in developed countries (World Bank 1994). In DCs, power plants consume 15-30 percent more fuel per unit of electricity than that of ICs (WRI 1994). Transmission and Distribution system losses represent a loss to DCs of about $30 billion a year through increased supply costs (Saunders and Gandhi 1994). Inadequate tariffs due to governmental policies and poor revenue collection due to inadequate metering, as well as poor accounting and billing, have led to large financial losses and difficulties in raising investment capital. While institutional building (training of power utility staff, modernization) has continued to progress, conflicts between government's role as owner and its role as operator of utilities, have affected sector performance. Opaque command and control management of the sector, poorly defined objectives, government interference in daily affairs, and a lack of financial autonomy have affected productive efficiency and institution performance (World Bank 1992).

To accommodate the projected growth in electricity demand, assuming no major gains in energy efficiency, DCs will require about US $1 trillion (in current terms) to finance future capital investments. In comparison with the total projected annual requirement for DCs of $100 billion for the early 1990s, the present annual rate of electricity related investment in developing nations is only around $50 billion. Even this present rate is proving difficult to maintain. Developing country debt, which averaged 23 percent of GNP in 1981, increased dramatically to 42 percent in 1987 and, although it has since declined to 37 percent due to improved economic performance and trade conditions, is still significant (World Bank, 1992). Capital-intensive power sector investments have played a major role in this observed increase. Investments required to meet growth of demand for energy in DCs will rise to an average of $200 billion per annum in the late 1990s, or 4 percent of GDP. Added to this, private investors are reluctant to re-enter those DCs that continue to experience difficulties in servicing their foreign debt (Saunders and Gandhi 1994).

The future expansion of the power sector in DCs also has serious environmental impacts to meet the growing demand. WDR estimates indicate that, under the worst scenario, emissions of pollutants from electric power will rise tenfold by 2030. In addition to the basic investments mentioned above, the World Bank, in the 1992 WDR, estimates incremental investment for energy-related environmental management programs in DCs in 2000 as follows:

*$2 billion for controlling particulate matter emissions from coal-fired power stations.

*$5 billion for reducing acid rain deposition from new coal-fired stations.

*$10 billion for switching to unleaded fuels, and for implementing controls on the main pollutants from vehicles.

*$10-15 billion for reducing emissions, effluents and wastes from industry.

*$3-4 billion per year by the end of the century would enable a major program of research, development, and demonstration projects for renewable energy to be undertaken.

Controlling emissions of particulates will raise investment costs by about 1 percent, or 0.04 percent of GDP. In areas where controls on sulfur dioxide and nitrogen oxides are necessary, a further 5-15 percent of capital costs (or 0.5 percent of the regions' GDPs) would be incurred if low-sulfur coal or natural gas were not available. With these investments, DCs will be able, in 2030, to produce ten times as much electric power as today, with lower emissions of particulates and acid rain-causing pollutants.

Taking account of the impact of energy efficiency and environmental considerations, the WEC (1993) estimates a broad order of magnitude figure for the cumulative investment requirements (at 1992 prices) of the world's energy industry over the next twenty-five to thirty years at around $30 trillion. By comparison world GDP in 1989 was approximately $20 trillion. The WEC estimates that the DCs could be investing in excess of $2 trillion (at 1992 prices) annually by the year 2020; over 50 percent of world annual energy investments. About $1.2 trillion annually will be needed to raise energy efficiency and environmental standards in the former USSR to the average level of the OECD.

Electricity, Environment and Regional Concerns

Although electricity is relatively benign in use, the generation of electricity is one of the world's major environmentally damaging activities. While the energy sector contributes 49 percent of greenhouse gases, electricity generation alone produces more than 25 percent of energy-related carbon dioxide emissions. During the past 20 years, half of all increases in energy-related carbon dioxide emissions were from electricity (Energy Analysis Program 1991). Most of the growth in world carbon dioxide emissions from 1971 to 1990 is due to the CEE and developing countries (Table 5).

Despite alternative energy sources such as wind, solar, and biomass, the largest segment of new electricity in the world is projected to come from coal firing in the next several decades, and this will bring related environmental problems along with it (U.S. Industrial Outlook 1994).

The expected growth of electricity generation in DCs described previously is confronted by a variety of technological, economic, and environmental problems. Although the electric power sectors in industrialized nations are concerned with environmental problems related mainly to generation, in many DCs environmental issues are not considered such a high priority. The

Table 5

CO_2 Emissions From Energy Use

	Million Tons of Carbon				
Year	World	OECD	CEEs	DCs	Coal%
1971	4380	2427	-	-	-
1980	5500	2750	1570	1180	37%
1985	5800	2640	1700	1460	-
1990	6550	2900	1700	1950	39%

Source: Various IPCC Reports.

problems of the electricity sectors in the developing world differ among regions and countries (Winje 1991).

Africa

Many African nations import oil, and indigenous commercial energy resources play a small role in domestic electric power generation. This practice has worsened the debt situation in these countries. In much of Africa, existing electricity systems are isolated, and consist of small generation units that have low efficiency and reliability. Therefore, the demand for electricity usually exceeds supply. Confronted with these basic problems, many African governments are concentrating mainly on improving and expanding existing systems, and believe that environmental issues in the power sector are relatively unimportant. Therefore, in this region, there is an urgent need for the development of national and regional electricity master plans, with assistance from industrialized nations (Winje 1991). In many parts of Africa there is substantial hydroelectric potential, but its exploitation has been subject to many environmental and social problems (Akosombo Dam in Ghana, Aswan Dam in Egypt).

Asia

The consumption of commercial energy in developing countries in the Asian region grew rapidly in the last two decades. Between 1980 and 1992 energy consumption grew at an annual rate of 5.6 percent in east Asia and the Pacific and 6.8 percent in south Asia. While the dependence of oil has decreased in many countries, the use of coal, an abundant resource in the region, has increased especially in China and India. China is currently the world's largest coal producer with an output of 1082 Mt followed by India. The consumption of coal is expected to increase rapidly in the next two decades. Although the percentages of electricity generated from coal are 92 percent for China and 70 percent for India, current electricity generation is inadequate to meet the needs of their growing economies and the improvements in people's living standards. China and India, which have almost 37 percent of the world's population (mostly rural and poor), are currently following a path of economic reform and will continue to depend on coal for electricity generation over the next two decades. Therefore, these nations will continue to be the largest regional sources of transnational and global environmental problems in the future. With an increasing awareness of regional and global environmental impacts of coal combustion, both China and India are increasingly searching for ways to minimize environmental impacts of power generation while focusing on problems such as inadequate supplies of electricity for economic growth and to improve living standards of poor rural populations. Another major problem facing countries in this region is the loss of power in transmission and distribution. When compared to the typical rates of 6-8 percent in the industrialized countries, these are enormous: China, 16 percent (UNICEF 1993); India, 22 percent; Pakistan, 28 percent; Bangladesh, 31 percent; South Korea, 12 percent; Sri Lanka, 18 percent; and Thailand and the Philippines, 22 percent each. In contrast, the United States and Japan had corresponding values of 8 percent and 7 percent respectively (Munasinghe 1991).

Apart from the above problems, nations in the region suffer from inefficiencies resulting from inadequate pricing and excessive governmental interference.

Latin America and the Caribbean (LAC)

Electricity generation in the LAC region is distributed evenly between hydroelectric and thermo-electric plants. The development of the power sector in many nations has been overshadowed by the general debt problem in Latin America. In spite of this, the environmental impact of electricity supply has been given increasing attention in the last 10 years. Many countries have begun to consider the environmental impacts of mining fossil fuels and constructing large hydropower and thermal power plants. In some cases reforestation projects are now required by law. Concerted international action in Latin America will ensure the development of an efficient electricity system in a sound environment (Winje 1991).

Eastern Europe (EE) and Former Soviet Union (FSU)

EE and FSU countries consume a larger amount of primary energy and electricity than industrialized countries in terms of energy intensity. Their electricity intensity is two to three times, and the energy intensity is three to four times, higher than that of developed nations. This is mainly the result of the existence of vast energy resources in the region, which were made available at highly subsidized prices. The inefficiency of energy generation, the poor quality of commonly used energy carriers such as coal and lignite, and the large portion of primary industries, contribute to these high ratios. Many of the above factors have also resulted in the emission of high levels of sulfur dioxide, nitrogen oxides, and total particulate matter. Cooperation with industrialized nations is needed to enable measures such as restructuring the fuel mix in the power sector, and implementing stack gas cleaning equipment, to occur (Winje 1991). Technology could be one solution to lower energy intensity levels. Historically, such technical advances have led to large reductions in the amounts of energy required for any given economic activity — for example, the electricity required to produce a ton of aluminium has declined steadily since the last century.

In Central Asia, another area of high hydroelectric potential, electricity planning is made difficult by conflicts with irrigation and by the problems faced by the newly independent states in continuing development towards an integrated system.

3 The Need For Sustainable Development

The increasing level of environmental pollution in both industrialized and developing countries as well as resource depletion, have led to a recognition of the need for ICs and DCs to find a less material intensive development path. In the past, industrial countries that faced a tradeoff between economic growth and environmental preservation invariably gave higher priority to the former. These richer countries have only recently awakened to the environmental consequences of economic progress. This model of economic and social development has been adopted by many third world regions. However, an increasing awareness by both ICs and DCs of the consequences of following such a path have led them to explore the concept of sustainable development. This is an approach that will permit continuing improvements in the present quality of life at a lower intensity of resource use, thereby leaving behind for future generations an undiminished or even enhanced stock of natural resources and other assets.

Economic, Environmental and Social Approaches

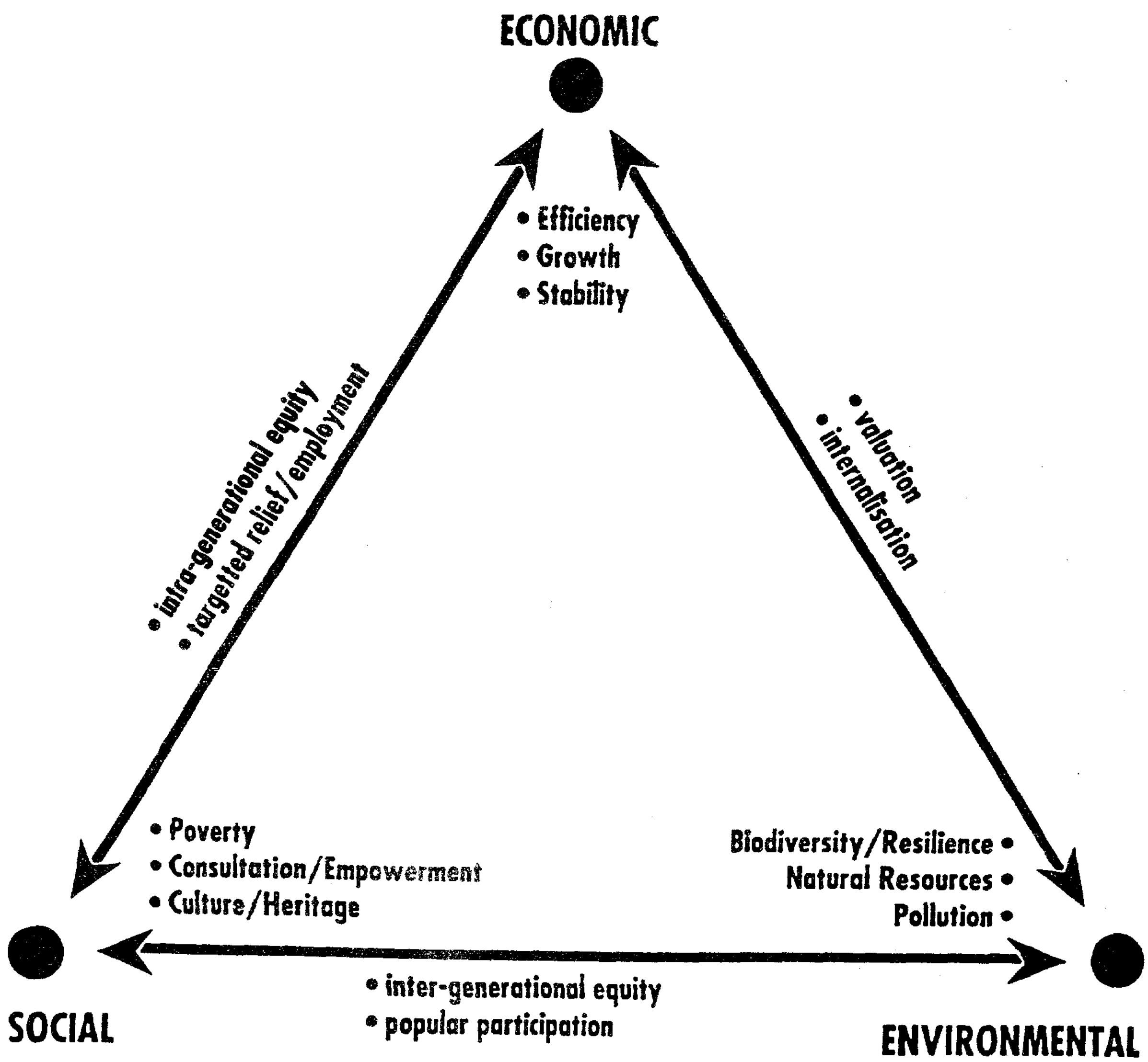
Sustainable development has three key elements—economic, environmental and social (see Figure 2). The economic approach to sustainability is based on the Hicks-Lindahl concept of the maximum flow of income that could be generated while at least maintaining the stock of assets (or capital) which yields these benefits (Solow 1986, Maler 1990). There is an underlying concept of optimality and economic efficiency applied to the use of scarce resources. Problems of interpretation arise in identifying the kinds of capital to be maintained (for example, manufactured, natural, and human capital) and their substitutability, as well as in valuing these assets, particularly ecological resources. The issues of uncertainty, irreversibility and catastrophic collapse pose additional difficulties (Pearce and Turner 1990).

The environmental view of sustainable development focuses on the stability of biological and physical systems. Of particularly importance is the viability of subsystems that are critical to the global stability of the overall ecosystem (Perrings 1991). Protection of biological diversity is a key aspect. Furthermore, "natural" systems may be interpreted to include all aspects of the biosphere, including human-created environments like cities. The emphasis is on preserving the resilience and dynamic ability of such systems to adapt to change, rather than conservation of some "ideal" static state.

The social concept of sustainability seeks to maintain the stability of social and cultural systems, including the reduction of destructive conflicts (UNEP et al. 1991). Both intra-generational equity (especially elimination of poverty), and inter-generational equity (involving the rights of future generations) are important aspects of this approach. Preservation of cultural diversity across the globe, and better knowledge concerning sustainable practices embedded in less dominant cultures, should be pursued. Modern society would need to encourage pluralism and strengthen empowerment and grass roots participation into a more effective decisionmaking framework for socially sustainable development.

Figure 2

The Economic, Social and Environmental Dimensions of Sustainable Development



Source: Munasinghe 1993a.

Given the foregoing three criteria for sustainable development, the rapidly increasing demand for energy, particularly electricity, in the DCs, and the corresponding increase in investment requirements, the need for a comprehensive and integrated conceptual framework for analysis and decisionmaking is evident. Sustainable energy options may be identified by using a framework that takes into account multiple actors, multiple criteria, multi-level decisionmaking, and many impediments and constraints. However, any discussion of a framework within which to define sustainable energy options would be incomplete without a delineation of the environmental and social implications of energy use. They can be broadly categorized into national, transnational and global issues.

National Issues

National environmental and social issues arising from energy use are mainly related to electricity generation. While electricity has relatively few environmental and health consequences at the point of end use, the same cannot be said for electricity generation. The extent and nature of impacts, however, differ among energy sources. Oil- and coal-fired plants not only have national impacts but also regional and global environmental and health effects. Even sources like wind power, geothermal energy, and ocean energy, which are perceived to be "clean," have some negative impacts on the surroundings. The environmental and social consequences of some typical energy sources are described below.

Fossil-fired Plants

In the case of oil- and coal-fired plants, a significant public health risk results from exposure to the large amounts of gaseous and solid wastes discharged in the combustion process. These emissions include sulfur dioxide, carbon monoxide, nitrogen oxides, hydrocarbons, polycyclic organic matter, and in the case of coal, additional pollutants include fly ash, trace metals, and radionuclides. The presence of these pollutants leads to increased incidence of respiratory disease, toxicity and cancer. Disposal of solid waste leads to health risks associated with leachate and groundwater contamination. Natural gas-fired plants pose a public health risk from nitrogen oxides and particulate emissions, but are significantly less hazardous to health in comparison with oil- or coal-fired plants. Coal mining, transportation and washing also have substantial adverse impacts on environment.

The contribution of fossil fuels to carbon dioxide emissions depends on the carbon content of the fuel. Fuel oil emits 87.7 percent as much carbon dioxide as coal, and natural gas only 58 percent for the same thermal content. Without control or treatment, coal emits more particulate matter (PM), sulfur dioxide, and nitrogen oxides, than any other fuel. While PM emissions in the case of oil and gas are negligible, coal emits almost 10 percent of its oil equivalent in weight as ash and other matter. Sulfur dioxide emissions depend on sulfur content of the fuels, while emissions of nitrogen oxides are not significantly different between fuels, with gas emitting only two-thirds that of coal.

Nuclear Plants

Nuclear fission reactors, currently producing almost 17 percent of electricity worldwide, were intended to replace fossil-fueled capacity in the medium-term. Safety concerns, driven by accidents at Three Mile Island and Chernobyl, have contributed to the current status of nuclear energy as neither politically nor economically attractive in many countries. However, in a few countries, such as France and Japan, nuclear reactors are used extensively. Though nuclear energy has the advantage that it emits none of the atmospheric pollutants of concern with fossil fuel technologies, the fission reaction does generate long-lived highly radioactive wastes; their ultimate disposal is extremely controversial. Nuclear power also causes groundwater contamination. It is more capital intensive than fossil fuel power generation. There is also a great deal of controversy about the true cost of nuclear power.

Studies indicate that occupational health risk, which may have inter-generational consequences, exists from exposure to radiation. Public health risks result from exposure to low-level radiation from power production, waste storage and waste disposal. High exposure to radiation is possible in the event of major accidents, with potential long-term health implications. While actual public risk may be relatively small, public fears of risks from nuclear plants and waste disposal sites are extremely strong and cannot be dismissed (often based on risk- averse reactions to potentially catastrophic but rare accidents).

Hydroelectricity

Nineteen percent of worldwide electricity is produced currently by flowing water, mostly in large hydroelectric dams that utilize reservoirs or natural steep drops and waterfalls. Since the capital investment requirements for large hydroelectric schemes are significant, many sites in DCs must compete for scarce capital. Hydroelectric power utilizes a renewable indigenous resource without producing air emissions or radioactive wastes. However, this technology is not entirely environmentally benign. Hydroelectric power generation has primarily local environmental and social consequences. These consist of the damage caused by dam construction: destruction of habitats and loss of local/national biodiversity, the inundation of productive land and forests, siltation, and possibly the loss of cultural sites and mineral resources. Water shed disturbance sometimes leads to increased flooding, and low flow in the dry season. (On major river systems, this can have transnational consequences causing significant political and social unrest over water rights).

Such environmental and social impacts of hydropower projects have recently led to public protest against proposed projects in South Asia and South America. Furthermore, still water reservoirs create ecological environments favorable to the spreading of parasitic and waterborne disease. Decades of experience have been developed internationally with mini and micro-hydro schemes that cascade many small run-of-the-river turbines. These designs are becoming a visibly popular means for providing local power supply and irrigation without the massive environmental and social impacts that have plagued some large hydro schemes. Micro-hydro projects are currently underway in India and Malaysia and other DCs. These projects also have the advantage of providing electricity to rural areas beyond the central grid.

Hydropower plants have many other advantages which include longer service life, lower staffing requirements, operational flexibility, reliability, and fast response time to changes in demand.

Solar Energy

Direct solar radiation is another vast potential energy source for electricity generation. Advances in solar thermal technologies and direct electricity generation by photovoltaics (PV) have reduced costs significantly over the past decade (Ahmed, 1994). While these techniques pose no significant occupational and health risks at the generation stage, some environmental impacts of solar thermal generation, may arise from the loss of land use resulting from its high land intensity. Solar energy is constrained by its limited applicability.

Geothermal Energy

Geothermal energy is harnessed in several countries (for example, the United States and the Philippines) by using geothermal steam to drive steam turbines. Cost competitive exploitation of geothermal energy with current technology is largely limited to the volcanically active Pacific "Ring of Fire" and the Mediterranean, where suitable steam reservoirs are located within one mile of the surface. Geothermal steam carries with it a number of atmospheric pollutants including carbon dioxide, mercury and radon. Under current technologies, the toxins are commonly reinjected into the reservoir. With commercialization of designs expected late in this decade, hot dry rock technology is expected to be competitive with conventional geothermal technology and fossil-fueled plants.

Biomass

A wide range of options exist for converting biomass into electric power. Dendrothermal power plants burn wood from fast growing species (grown on a dedicated plantation), in boilers, to generate electricity through a conventional steam cycle. Most potential applications are for remote power supply in DCs. Concerns about the effects of dedicated fuelwood plantations, on the local environment and competing land uses, impose major constraints on the widespread adoption of dendrothermal power supply schemes.

It is economical to use biomass for energy purposes only where it is available as a byproduct of other processes. Crop residues, agricultural waste, and animal dung produced in DCs are currently used as fuels, mainly by the poor.

Another source of biomass for power generation is municipal solid waste. High temperature incinerators for municipal solid waste have been developed in Germany and the United States. The public has voiced opposition to incineration in both countries due to concerns over emissions of dioxin, furans and other toxins that are released when plastics are burned. Virtual elimination of toxic effluents is achieved in some of the new high temperature designs that utilize a slanted bed to ensure total combustion and wet scrubbers. A 25 MW incinerator can consume about 400,000 tons of municipal solid waste each year, thereby reducing the volume of waste ash for disposal. In addition to energy recovered and reducing urban waste disposal problems, leading edge technologies for waste incineration do not emit more atmospheric greenhouse gases than if the wastes were allowed to decay. In addition to the option of direct incineration, small power plants that burn landfill gases (mostly methane) have been employed for decades around the world. The ultimate potential of municipal solid waste incineration and landfill gas plants as an energy source, is limited both by public concern over emissions and by the shortage of concentrated sources of solid waste. In tropical areas, the water content of municipal solid wastes reduces its attractiveness as a fuel.

Wind Power

Large grid-connected wind generators (75kW-450kW), configured in multi-turbine "wind farms", now supplement fossil fuel capacity in a number of countries. Research is currently underway in the United States on combined wind and gas turbine power supply schemes that would provide reliable power on demand, at minimal cost. Although wind generators do not produce air or water emissions, planners often face public opposition since the larger turbines do present a visual impact on the landscape, emit acoustic noise, generate electromagnetic interference, and present a hazard to birds.

Ocean Energy

Pilot plant experience has indicated that temperature differences of 20 degrees centigrade between surface waters and waters about 1000 meters below are sufficient for economic power generation. As a large proportion of the tropical oceans contain such thermals, a vast potential resource is available. Due to significant capital requirements and risks inherent in an unproven technology, no commercial plants have been built to date. In addition, this technology poses some environmental concerns about effects on sea life and atmospheric release of carbon dioxide stored in deep ocean waters.

Transnational Issues

Acid deposition is perhaps the most serious of the transnational issues faced today. Acid deposition is a result of oxides of sulfur and nitrogen that originate from fossil fuel combustion, falling to the ground as particulates and acid rain. Coal- and oil-fired power stations emit significant amounts of sulfur dioxide and nitrogen oxides into the atmosphere. The transport of sulfur dioxide occurs over long distances (greater than 1000 km), causing the deposition of emission products over national boundaries. This may result in sensitive ecosystems receiving depositions of sulfur well above their carrying capacity. Acid depositions caused by sulfur and nitrogen oxides result in damage to trees and crops, and sometimes extend to acidification of streams and lakes, resulting in destruction of aquatic ecosystems. They also lead to the corrosion, erosion, and discoloration of buildings, monuments and bridges. Indirect health effects are caused by the mobilization of heavy metals in acidified water and soil (IAEA 1991).

Other important transnational issues include environmental and health impacts of radiation due to severe nuclear accidents (Chernobyl), oceanic and coastal pollution due to oil spills (Amico Cadiz, Exxon Valdez and Braer), downstream siltation of river water in one nation due to deforestation of water sheds and soil erosion in a neighboring country, and changes in hydrological flow and water conditions caused by dams.

Global Issues

The increase in atmospheric concentrations of CO_2 and other radiatively active trace gasses (N_20, CH_4 and chlorofluorcarbons, or CFCs) has led to an increase in global mean temperatures, or global warming. According to a study conducted by the intergovernmental panel on climate change (IPCC), increases in greenhouse gas concentrations from anthropogenic activities are believed to have resulted in mean surface temperature increases of 0.3 to 0.6 degrees centigrade over the last century. While the study does not suggest that the case for global warming is fully established, several important issues remain unsolved. The warmest year for the planet Earth since measurements of surface temperatures were initiated was in 1990. Six of the seven warmest years since 1850 have all occurred since 1980. Changes in recent rainfall patterns, and frequency of storms, may also be attributable to the phenomenon. Over the last one hundred years global sea level has increased by 10 to 20 cm (IAEA 1991). These climatic changes may have contributed to natural disasters, such as the floods in Bangladesh and serious drought conditions in Africa, which resulted in extremely high social costs— high mortality, the spread of diseases such as typhus and cholera, widespread starvation/malnutrition, and significant population displacement.

The relative contribution of electricity generation to overall global warming (mainly in the form of CO_2 emissions) has been estimated at about 25 percent compared to about 14 percent caused by deforestation. Of this amount, coal and oil each contribute about 40 percent of anthropogenic carbon dioxide emissions, and gas about 15 percent. OECD and other European countries account for about 75 percent of global fossil fuel CO_2 emissions, at present. Energy consumption as a whole is the single largest contributor to greenhouse gas emissions in developing countries. While the use of traditional fuels is declining as a share of energy supply in many developing countries as a result of growing prosperity, India and China will be forced to increase coal-fired generation through domestic energy sources to meet the growing energy needs of their citizens.

Given the considerable problems faced by the power sector in DCs, the additional growing concerns about the environmental consequences of energy use considerably complicate the policy dilemma facing the DCs. Developing countries share the deep worldwide concerns about environmental degradation, and some have already taken steps to improve their own natural resource management as an essential prerequisite for sustained economic development. However, they also face other urgent issues like poverty, hunger and disease, as well as rapid population growth and high expectations. This paucity of resources constrains the ability of DCs to undertake costly measures to protect the global commons.

The challenge facing the developing world is how to harmonize development goals and the elimination of poverty (which will require increased use of energy), with environmental goals without worsening their weak economies. In 1992 per capita income in low income developing nations was almost one-sixtieth of that in the high income nations ($390 in low income countries versus $22,600 in high income countries). Correspondingly, per capita energy consumption in low income countries was 338 Kg of oil equivalent as compared to 5,101 Kg of oil equivalent in high income countries (WDR 1994).

The disparity in both per capita income and energy use among different countries also raises additional issues in the context of current global environmental concerns. Fossil-fuel related carbon dioxide accumulation in the atmosphere is a relevant example. The developed countries accounted for over 80 percent of such cumulative worldwide emissions during 1950-86 — North America contributed over 40 billion tons of carbon; Western and Eastern Europe emitted 25 and 32 billion tons respectively, while the DCs share was only about 24 billion tons. On a per capita basis the contrasts are even more stark, with North America emitting over twenty times more and the developed countries as a whole being responsible for over eleven times as much total cumulative carbon dioxide emissions as the DCs. The DC share would be even smaller if emissions prior to 1950 were included. Clearly, any reasonable growth scenario for developing nations that followed the same material-intensive path as the industrialized world, would result in unacceptably high levels of future greenhouse gas accumulation as well as a more general depletion of natural resources.

Up to now, scientific analysis has provided only broad and rather uncertain predictions about the degree and timing of potential global warming. However, it would be prudent for humanity to buy an "insurance policy" in the form of mitigatory actions to reduce greenhouse gas emissions. Ironically, both local and global environmental degradation might affect developing nations more severely, since they are more dependent on natural resources, while lacking the economic strength to prevent or respond quickly to increases in the frequency, severity and persistence of flooding, drought, storms, and so on. Thus, from the DC viewpoint, an attractive low cost insurance premium would be a set of inexpensive measures that could address a range of national and global environmental issues without hampering development efforts.

The report of the Brundtland Commission (WCED 1987), which has been widely circulated and accepted, has presented arguments along the theme of sustainable development, which consists of the interaction of two components: needs, especially those of the poor segments of the world's population; and limitations, which are imposed by the ability of the environment to meet those needs. The development of the presently industrialized countries took place in a setting which emphasized needs and de-emphasized limitations. The development of these societies have effectively exhausted a disproportionately large share of global resources — broadly defined to include both the resources that are consumed in productive activity (such as oil, gas and minerals), as well as environmental assets that absorb the waste products of economic activity and those that provide irreplaceable life support functions (like the high altitude ozone layer). Indeed, some analysts argue that this development path has significantly indebted the ICs to the larger global community.

The division of responsibility in this global effort is clear from the above arguments. The unbalanced use of common resources in the past should be one important basis on which the developed and developing countries can work together to share and preserve what remains. The ICs have already attained most reasonable goals of development and can afford to substitute environmental protection for further growth of material output. On the other hand, the DCs can be expected to participate in the global effort only to the extent that this participation is fully consistent with and complementary to their immediate economic and social development objectives.

4 A Framework for Sustainable Energy Development

The broad rationale underlying all national level planning and policymaking is the need to ensure the best use of scarce resources, in order to further socio-economic development efforts and improve the quality of life for citizens. Power and energy planning must also be part of and closely integrated with overall economic planning and policy analysis, to meet many specific, interrelated and frequently conflicting national objectives. Specific goals might include: (a) ensuring economic efficiency in the supply and use of all forms of energy, to maximize growth— other energy efficiency-related objectives are energy conservation and elimination of wasteful consumption, and saving scarce foreign exchange; (b) raising sufficient revenues from energy sales, to finance sector development; (c) meeting the basic energy needs of the poor, and income redistribution; (d) diversifying supply, reducing dependence on foreign sources, and meeting national security requirements; (e) contributing to development of special regions (particularly rural or remote areas), and priority sectors of the economy; (f) price stability; (g) preserving the environment; and so on.

Integrated Approach

Successful planning and implementation of national energy programs must explicitly take account of the role of the energy sector in economic development relative to those of the other parts of the economy. This will require an integrated approach that will help decisionmakers in formulating policies and providing market signals and information to economic agents that encourage more efficient energy production and use. Summarized in Figure 3 is such an approach to decisionmaking which emphasizes a hierarchical conceptual framework for sustainable energy development (SED) that can be implemented through a set of energy supply and demand management policies.

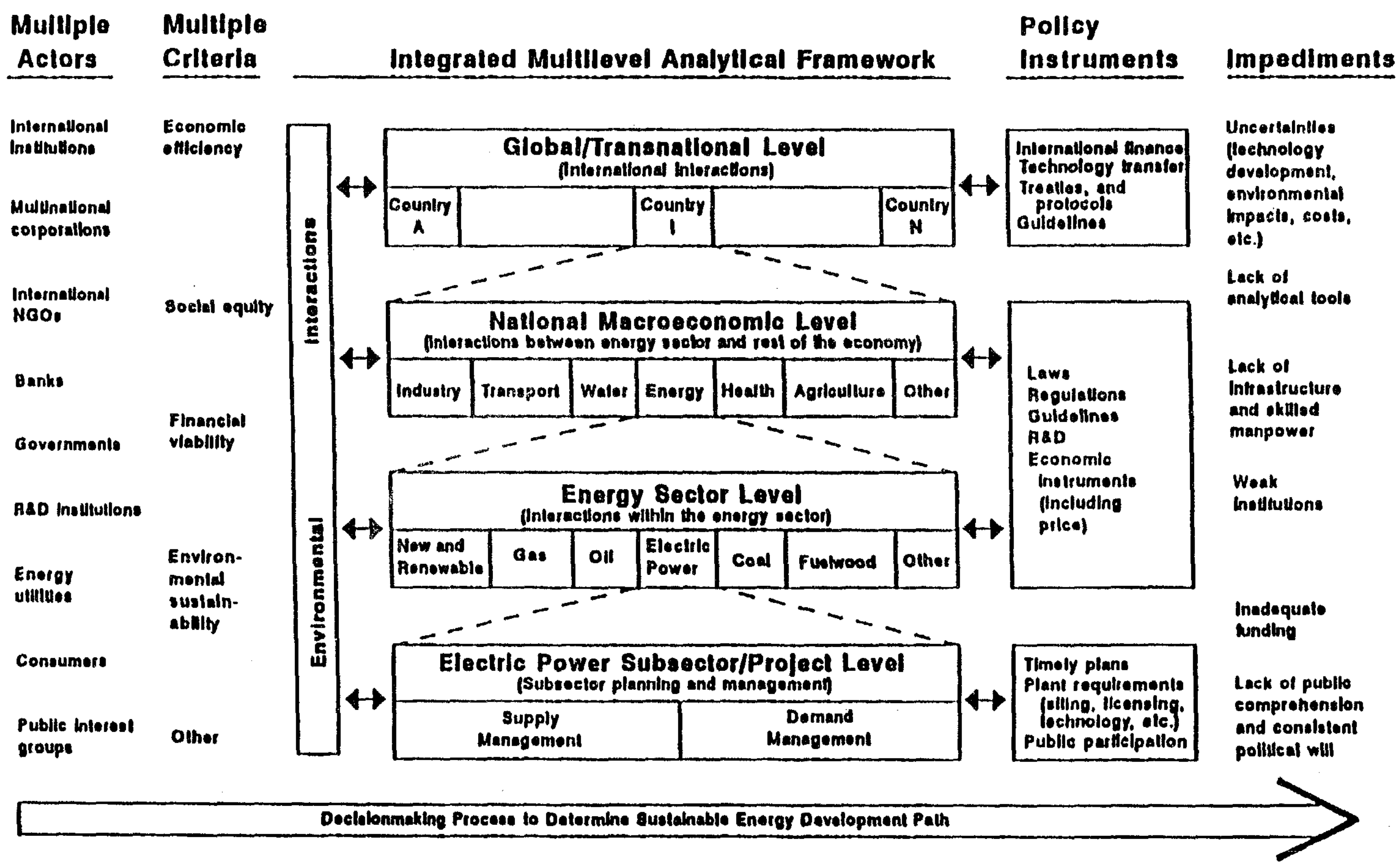
The core of the SED framework is the integrated multilevel analysis shown in the middle column. Although SED is primarily country-focused, at the global level it is recognized that there are transnational energy-environmental issues. Thus individual countries are embedded in an international matrix, and economic and environmental conditions at this global level will impose exogenous inputs or constraints on decisionmakers within countries.

The next hierarchical level in the figure focuses on the multi-sectoral national economy, of which the energy sector is a part. This suggests that energy planning requires analysis of the links between the energy sector and the rest of the economy. Such links include the energy needs of user sectors (for example, industry, transport, and agriculture), input requirements of the energy sector, and impact on the economy of policies concerning energy prices and availability.

The intermediate level of SED treats 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 the different energy sub-sectors, substitution possibilities, and the resolution of any resulting policy conflicts.

Figure 3

Conceptual Framework for Sustainable Energy Development



Source: Munasinghe 1991.

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 resource evaluation, planning and implementation of projects is carried out by line institutions (both public and private).

In practice, the various levels of SED merge and overlap considerably, requiring that (inter-) sectoral linkages should be carefully examined. Energy-environmental 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 considerations into national energy policies.

SED facilitates policymaking and does not imply rigid centralized planning. Thus, such a process should result in the development of a flexible and constantly updated energy strategy designed to meet national goals. This national energy strategy (of which the investment program and pricing policy are important elements), may be implemented through energy supply and demand management policies and programs that make effective use of decentralized market forces and incentives.

Consequently, SED implies improvements in overall economic efficiency through better energy management. As shown in Figure 3, a variety of policy instruments are available for decisionmakers for instituting sound energy management. While formulating policy, it is also desirable to consider the interests of multiple actors (shown in the figure), ranging from international institutions to local energy users. This figure also indicates the most important impediments that limit effective policy formulation and implementation.

New investments offer a good opportunity to pursue sustainable energy development. In ten years, new plants will account for more than half of the industrial output of developing countries and in twenty years, for practically all of it. As a result, it will be possible to have a major impact by putting in place policies, legislation, mechanisms, systems, and incentives that facilitate sustainable energy development.

Identifying Sustainable Energy Options: "Win-Win" Options vs. Tradeoffs

The primary objective of sustainable energy development (SED) is to maximize welfare, while maintaining or increasing the stock of economic, ecological, and sociocultural assets over time (to ensure the sustainability of income and intragenerational equity) and provide a safety net to meet the basic needs and protect the poor (thereby advancing intergenerational equity). In considering sustainable energy options, policymakers must therefore take into account all three aspects of sustainable development (that is, economic, social and environmental). Options that lead to improvements in all three indices are referred to as "win-win" options. Once "win-win" options are realized, policymakers are able to make tradeoffs among other available options.

The incorporation of environmental externalities into decisionmaking is particularly important in the power sector, where environmental concerns (ranging from greenhouse gas emissions of fossil-fueled plants to the impacts of inundation at hydro plants) have posed increasingly difficult constraints to project implementation. It is also clear that in order for environmental concerns to play a real role in power sector decisionmaking, one must address these issues early—at the sectoral and regional planning stages, rather than only at the stage of project environmental assessment.

Unfortunately, as soon as one is dealing with power sector issues at this aggregate planning level, the application of many project-level valuation techniques becomes extremely difficult, for two main reasons. The first is the nature of the impacts themselve: the health effects of pollutants from coal-fired generating stations, the potential loss of biodiversity associated with large scale hydro reservoirs, and the impacts of greenhouse gas emissions, are all exceptionally difficult to value. Indeed, attempts to do so would very likely focus attention on the validity of the valuation techniques themselves, rather than the policy trade-offs that must be made. The second reason concerns the scale of analysis. Many techniques used are most appropriate at the micro-level: the use of the contingent valuation approach is much more valid where respondents can be asked specific questions about impacts of a particular project to which they can relate. However, this may be very difficult to apply in situations where one is dealing with a potentially large number of technology, site and mitigation options.

It is in these kinds of situations that the techniques of multi-criteria analysis (MCA) may be applied. Such techniques first gained prominence as practical evaluation tools in the 1970s, when the intangible environmental externalities lying outside conventional CBA methodologies were increasingly recognized. It also met one objective of modern decisionmakers, who preferred to be presented with a range of feasible alternatives as opposed to one "best" solution. MCA allows for the appraisal of alternatives with differing objectives and varied costs and benefits, which are often assessed in differing units of measurement.

Multi-criteria analysis offers policymakers an alternative when progress toward multiple objectives cannot be measured in terms of a single criterion (that is, monetary values). Take the case of an efficient fuelwood stove—an end use option for sustainable energy development (see section on SED Options Matrix). While the economic value of an efficient fuelwood stove is measurable, its contribution to social and environmental goals is not easily valued monetarily. As shown in Figure 4, outward movements along the axes trace improvements in three indicators: economic efficiency (net monetary benefits), social equity (improved benefits for the poor), and environmental benefits (reduced pollution and deforestation).

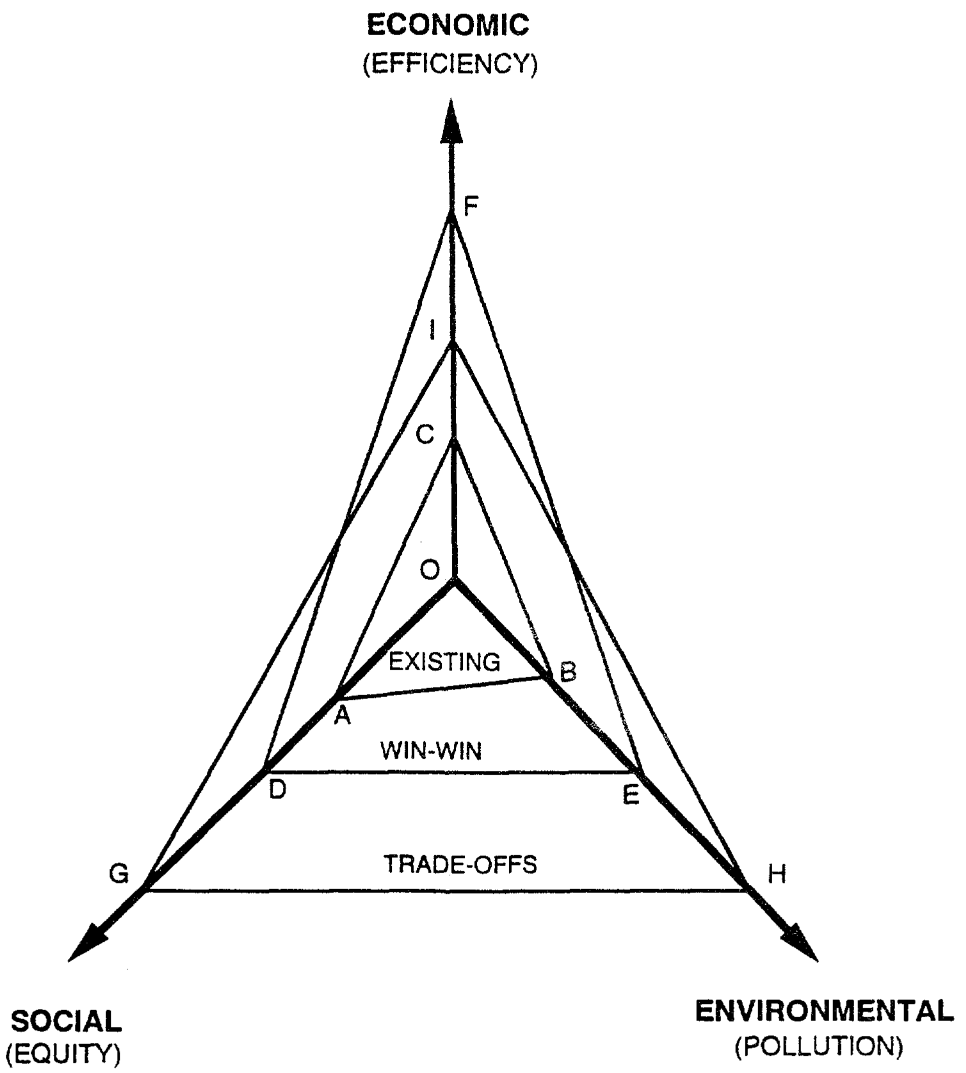
We may assess the policy options as follows. First, triangle ABC describes the existing fuelwood stove where economic efficiency is moderate, social equity is low, and overall environmental impact is worst. Next, triangle DEF indicates a "win-win" future option in which all three indices improve, as could occur with an improved fuelwood stove that provided efficient energy and health benefits to the poor. The economic gains to low income households would include monetary savings from reduced fuelwood use and increased productivity from reductions in acute respiratory infections, lung disease and cancer caused by pollutants in biomass smoke. Social gains would accrue from the fact that the rural poor benefit the most from this innovation—for example, due to the reduced time spent on collecting fuelwood, thereby, increasing time spent on other productive activities, and the lightened health and labor burden on women and children. The environmental benefits occur because a lower demand for fuelwood will reduce deforestation and reduce green house emissions resulting from inefficient combustion (Barnes, Openshaw, Smith and Van der Plas 1994).

After realizing such "win-win" gains, other available options would require tradeoffs. In triangle GIH, further environmental and social gains are attainable only at the expense of sharply increasing costs. For example, shifting from fuelwood to LPG or kerosene as a fuel may increase economic costs, while yielding further environmental and social benefits. In sharp contrast to the move from ABC to DEF, which is unambiguously desirable, a policymaker may not wish to make a further shift from DEF to GIH without knowing the relative weights that society places on the three indices. Such preferences are often difficult to determine explicitly, but it is possible to narrow the options. Suppose a small economic cost, FL, yields the full social gain DG, while a large economic cost, LI, is required to realize the environmental benefit EH. Here, the social gain may better justify the economic sacrifice. Further, if purely budgetary constraints limit costs to less than FK, then

Figure 4

Complementarities and Tradeoffs

Among the Three Main Dimensions of Sustainable Development



Source: Munasinghe 1993b.

sufficient funds exist only to pay for the social benefits, and the environmental improvements will have to be deferred.

A recent World Bank study of power system planning in Sri Lanka demonstrated the versatility of the MCA approach (see section on SED Options Matrix, for details). In this case, end-use energy efficiency measures provided "win-win" options (that is, they were superior to all other alternatives on the basis of air quality, biodiversity loss, and economic costs). Conversely, several prominent hydropower projects could be excluded because they performed poorly in terms of both biodiversity loss and economic costs.

In many countries, especially those in the developing world, inappropriate policies have encouraged wasteful and unproductive uses of some forms of energy. In such cases, better energy management could lead to improvements in economic efficiency (higher value of net output produced), energy efficiency (higher value of net output per unit of energy used), energy conservation (reduced absolute amount of energy used), and environmental protection (reduced energy related environmental costs).

However, it may not always be possible to satisfy all of the above goals simultaneously. For example, in some DCs where the existing levels of per capita energy consumption are very low and certain types of energy use are uneconomically constrained, it may become necessary to promote more energy consumption in order to raise net output (thereby increasing economic efficiency). In spite of this particular case, there are many instances where it may be possible to increase energy efficiency while decreasing energy consumption.

The economic efficiency criterion which helps us maximize the value of net output from all available scarce resources in the economy (including energy), should effectively subsume purely energy-oriented objectives such as energy efficiency and energy conservation. Furthermore, the costs arising from energy-related adverse environmental impacts may be included (to the extent possible) in the energy economics analytical framework, to determine how much energy use and net output that society should be willing to forego, in order to abate or mitigate environmental damage.

Energy use and generation in the developingworld can be improved in two main ways to make them more sustainable. First, energy efficiency can be increased by supply and demand side improvements. Along with this, environmentally more benign technologies can be introduced. Fuel switching and renewables are relevant in the latter case. In addition, options such as price reform and institutional and regulatory reform can be further implemented in order to achieve the required objectives of SED.

Improving Energy Efficiency

"Energy efficiency," or the efficiency with which energy is produced and used, is one of the most widely advocated methods of reducing pollution. During the past two centuries, the efficiency of energy producing and using activities, as measured by the amount of energy needed to provide a given output or service, has improved by factors ranging between 50 and 100, sometimes more (Anderson and Cavendish 1992). However, the demand stimulated by subsequent reduction of the cost of energy, the expanding areas of energy utilization, and the growth of population and industry, has dramatically expanded energy use. During the present century, during which energy efficiency grew by factors of more than 10 in key sectors such as electricity, world commercial energy consumption has increased tenfold—an average growth rate of 2.5 percent a year (Anderson and Cavendish 1992).

The carbon intensity of world economic product dropped by more than 20 percent during the period 1970-1986, and 75 percent of this was achieved due to energy efficiency measures. In the future, DCs offer even greater potential to improve energy efficiency and a corresponding decline in carbon emissions. In 1990, OECD countries were able to produce a unit of economic output using little more than half the energy required by the DCs and CEE countries.

There is a spectrum of technological options which the DCs could potentially utilize in order to improve energy efficiency. Among these, improvements in both the supply, and the end use of energy, should be considered.

Supply Side Improvements

Among the short-term technological options for the DC power sector, reducing transmission and distribution losses, and improving generation plant efficiencies appear to be the most attractive. Recent studies show that up to a certain point, these supply efficiency enhancing measures yield net economic savings or benefits that are several times the corresponding costs incurred (Munasinghe 1990b). Total energy losses in DC power systems are estimated to average in the 16 to 18 percent range. The average system losses in South Asia have been estimated at 17 percent and in East Asia at 13 percent (Munasinghe 1991). A comparison with OECD countries presents a more grim situation. It has been estimated that older power plants in many developing countries consume 18 to 44 percent more fuel per KWh produced than is the norm in OECD countries and utilities suffer transmission and distribution losses 2 to 4 times higher (Levine et al. 1991).

The consequences of reducing these losses can be quite important. On the basis of previous estimates of capacity requirements, a 1 percentage point reduction in losses per year would reduce required capacity by about 5 GW annually in the DCs. The estimated savings in capital investment would be around 10 billion dollars per year. Meanwhile, the Agency for International Development (USAID 1988) has estimated that the average heat rate of DC power plants is around 13,000 Btu/kWh, compared to 9,000-11,000 Btu/kWh if these plants were operated efficiently. The energy savings and positive environmental consequences of efficient plant operation are quite significant.

The use of modern electricity generation with high technical efficiencies, such as combined-cycle power stations, is beneficial to the environment and resource conservation, but these techniques require high investment and technical expertise. Therefore, they may not be feasible for use in financially troubled developing nations. There is an acute need for increased research in cost-effective, efficient, energy supply techniques.

Demand Side Improvements

Significant gains in energy efficiency can also be achieved by conservation on the demand side. Johansson et al. (1987) provides an insightful review of the developments that have been taking place in end-use technologies which can have a major impact on energy efficiency. These technologies, which were developed in the industrialized countries as a response to the oil price escalation in the seventies, can be easily applied to achieve more efficient lighting, heating, refrigeration, and air conditioning around the developing world.

Since major demand growth in DCs is expected over the next few decades, and technologies and appliances are generally based on 1970s designs, a number of authors have concentrated on the gains in overall electricity system efficiency that are possible from end-use efficiency improvement programs in DCs. The National Energy Conservation Program (PROCEL) in Brazil is a case in point. This program advanced the development and commercialization of a number of energy-efficient lamps, reflectors for fluorescent fixtures, and building control systems. These technologies are now manufactured and sold in Brazil, and their adoption has provided an estimated 1.1 TWh of electricity savings in 1989. For the residential sector, most of the potential cost-effective savings come from the adoption of efficient refrigerators, air conditioners and compact fluorescent lamps

(CFLs). The cost of conserved energy (CCE), which is a measure of annualized increased capital costs divided by kWh saved over the life of the device, can be evaluated for each improved technology. Under moderate economic assumptions, the CCE of improved air conditioners, improved refrigerators, standard fluorescent lamps, and CFLs, relative to incandescent bulbs in Brazil, are 3.2c/kWh, 3.0c/kWh. 6.1c/kWh and 3.1c/kWh, respectively; all well below the marginal cost of residential electricity supply of 12c/kWh. Analysis of a proposed program to induce the adoption of efficient appliances in seven categories could reduce residential demand by 33 TWh/year, or 31 percent of projected residential demand, in Brazil by 2010 at an average annual cost (CCE) of 3.1c/kWh (Khatib and Munasinghe 1992).

One major reason DCs hesitate to adopt these technologies is their belief that this will increase costs dramatically. However, the OTA study shows that when all the system-wide financial costs are accounted for, energy efficient equipment usually can provide the same energy services at a lower installed capital cost than less efficient equipment (OTA 1991). Unfortunately, consumers who purchase end-use equipment see the increase in capital costs of more efficient designs, but not the decrease in capital costs as fewer power plants have to built to provide a given level of energy service.

In DCs, an important barrier to demand side energy improvement is lack of information about the availability and reliability of new energy efficient equipment. Other reasons such as subsidized and low energy prices, absence of competitive end-use markets, and government-regulated weak energy supply sources, are also impediments to efficient use of energy on the demand side. Few energy supply enterprises in DCs have the necessary customer information base to predict results of end-use efficiency improvements. However, the potential for demand side improvements is attractive. Technically proven cost-effective end-use conservation techniques can save DCs 10 to 30 percent of industrial sector energy consumption and 10 to 25 percent of power sector energy consumption (Saunders and Gandhi 1994).

Construction for both residential and commercial buildings has special importance because of the large amount of energy consumed within interior work spaces. For example, over one-third of the total energy consumed in the US is used to heat, cool, and light buildings or to operate equipment, such as computers, used by the occupants of buildings (Glicksman 1991). Although DCs in colder regions may have similar energy requirements, those countries which are closer to the tropics will require much less energy for heating purposes. Some of the energy consumption for cooling purposes may be relevant in these cases.

Although new technologies, such as "smart windows," which control the solar energy entering a building, are being developed, much of the improvement in the energy efficiency of buildings has been achieved by applying technologies already at hand.

A number of market-based incentives have been proposed to improve building standards. These include efficiency standards and labeling for buildings, appliances, and lighting; utility fees, offsets, and rebates; and urban infrastructure improvements to battle summer heat islands and greenhouse gases (Rosenfield 1991).

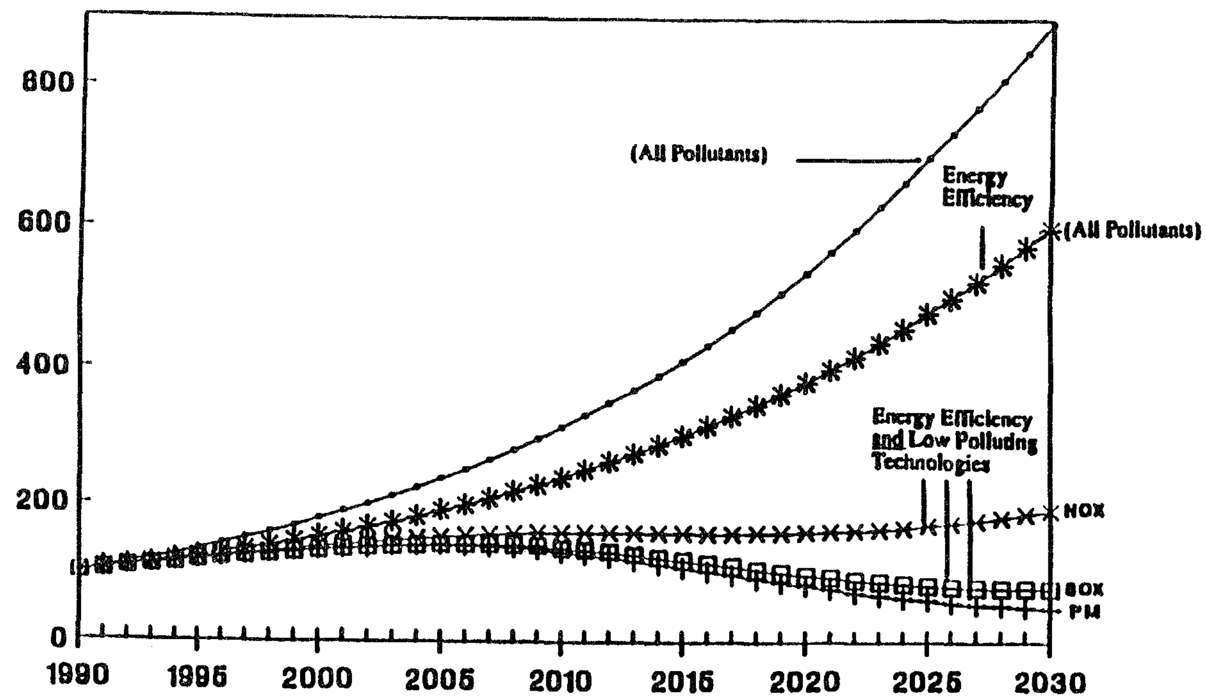
Making these efficient electricity end-use technologies widely available in DCs could contribute in important ways to a global effort to increase electricity end-use efficiency, thus reducing growth in electricity supply, local environmental and social impacts, and in greenhouse gas emissions (Lawrence Berkeley Laboratory 1991).

Cost Savings

Increasing efficiency in energy production and use in DCs will result in large savings in the public and private sectors as pointed out by Anderson and Cavendish (1992). They conclude

Figure 5

Three Scenarios of Emissions from Electricity Generation in Developing Countries, 1990-2030 (Index: 1990 = 100)



Source: Anderson and Cavendish 1992.

that the approximately $125 billion per year of cost-savings estimated for electricity production in DCs, for instance, amounts to several times the financial requirements of accelerated programs in each of several other sectors such as education, water and sanitation, health, soil erosion control, agricultural research and extension, and family planning. Price and institutional inefficiencies in energy supply are not only damaging to the (environmentally responsible) growth of the energy industry itself in DCs, but are a huge burden to the rest of the economy.

Figure 5 emphasizes the importance of energy efficiency. The reduction of pollution emissions this method alone can achieve is significant, even in the absence of other measures. The figure also illustrates the dramatic reduction of pollution when low polluting technologies are introduced simultaneously.

Implementing Environmentally More Benign Technologies

In the long-term, DCs will need to rely on more advanced technological options which are currently being developed in industrialized countries. As discussed earlier, power generation capacity in DCs is expected to nearly double by the turn of the century, and will increase further thereafter. This provides many opportunities for developing nations to add state-of-the-art technologies which have been designed with consideration of economic and environmental criteria. Clean coal technologies, cogeneration, gas turbine combined cycles, and steam-injected gas turbines, are part of this menu of technologies which have important potential in developing nations. Similar applications will become available for emission control technologies. However, the DCs will look to the industrialized nations to provide leadership in refining and testing these technologies before they are implemented in the developing world.

Fuel switching, and the use of renewable energy sources, are two important technology changes which should be implemented in the developing world.

Fuel Switching

The substitution of primary energy sources in power generation is an important potential means of achieving dual benefits which are evident in the case of substituting natural gas for coal or oil. The economic benefit of natural gas substitution comes from either import substitution for petroleum products or releasing these products for export. As a second benefit, natural gas firing typically achieves a 30-50 percent reduction in carbon emissions. Many Asian countries are endowed with significant resources of natural gas, including Malaysia, Indonesia and Thailand.

The fuel used for electricity generation often has high sulfur content, thus causing a high level of atmospheric pollution. A considerable reduction of these emissions can be achieved by substituting quality coal or other fuels for low-grade coal. Investing in gas- and oil-fired power plants would also reduce carbon dioxide emissions. This should be considered more carefully, however, because it would mean increased dependence on imported oil or gas for most DCs (Winje 1991).

Finally, when considering fuel switching, the relevant time frames should be taken into account. Historical experience suggests that even under strong incentives, roughly fifteen years to switch from one fundamental production process (for example, basic oxygen process steel making) to newer processes, throughout a national industrial sector. Major fuel switches in energy systems have taken even longer—on the order of twenty-five years (Clark 1991). This has important bearing on the efficacy and feasibility of proposals for fuel substitution.

Renewable Energy Sources

The World Energy Council (WEC) estimates that, under an Ecologically Driven Scenario, the contribution of new renewable energy sources (defined as total renewable energy sources minus traditional biomass and large hydro) will reach 13-14 percent of total energy use by 2020. Total renewable energy use is expected to reach 30 percent, nearly a tenfold increase over 1990 figures (Darnell et al., WEC, 1992). This would allow for a reduction of 30 percent in annual global energy-related carbon dioxide emissions. It is important to emphasize that this Ecologically Driven Scenario assumes almost immediate radical changes in energy policy and consumer behavior, leading to a decline in global energy intensity over the next thirty years. These changes would have to occur at a rate three times faster than average annual rates achieved over the past fifteen years (Jefferson 1992). Jefferson provides a more conservative estimate, predicting that new renewables would account for not more than 8.5 percent of total primary energy supply by 2020, with fossil fuels still accounting for up to 70 percent of total primary energy supply.

In one recent scenario, Johansson et al. (1992) estimates that, given the appropriate technological and financial support, renewable sources of energy could meet three-fifths of the world's energy market (with contributions from hydro power, wind and solar power, and biomass) and two-fifths of the market for fuels (mostly biomass-derived) used directly by 2050[1].

[1] This renewables-intensive energy scenario assumes an eightfold increase in world economic output by 2050, as projected by the Response Strategies Working Group of the Intergovernmental Plan on Climate Change (IPCC). In this forecast the demand for electricity increases 265 percent between 1985 and 2050, in spite of a marked increase in energy efficiency.

Provided that energy efficiency and renewable energy promotion measures are aggressively implemented, the authors estimate that global carbon dioxide levels could be reduced to 75 percent of 1985 levels by 2050.

The range of estimates clearly indicates the level of uncertainty regarding the potential of renewable energy to meet global energy demand within the next thirty years. However, while statistics vary, it is evident that non-conventional sources of energy have a key role to play in meeting energy needs in an efficient and cost-effective manner, particularly in DCs where most of the growth in demand will occur.

Price Reform

Economically efficient pricing policies serve a dual role in the electric power sector, and are especially important in the context of the developing world. Prices that reflect the true value of the resources employed in the supply of electric power, ensure that consumers are given the correct economic signals to use electricity in the most efficient manner. Efficient prices also indicate consumer demand to the power utility, which can accordingly augment supply capacity. Finally, correctly set prices ensure that the power sector is able to internally generate the financial resources required to maintain the requisite investment levels, and thus operate the sector efficiently.

In the past, electric power pricing policy in most countries was determined mainly on the basis of financial or accounting criteria. The practice of raising sufficient sales revenues to meet operating expenses and debt service requirements, while providing a reasonable contribution towards capital needed for future power system expansion, is an example. However, there has recently been increasing emphasis on the use of economic principles to produce and consume electric power efficiently, while conserving scarce resources. This is especially relevant in the DCs where a great deal of attention has been paid to the use of marginal cost pricing policies.

A comprehensive approach to power pricing recognizes the existence of several objectives or criteria, not all of which are mutually consistent. First, national economic resources must be allocated efficiently not only among different sectors of the economy, but within the electric power sector itself. Second, certain principles relating to fairness and equity must be satisfied. These include (a) fair allocation of costs among consumers according to the burdens they impose on the system, (b) assurance of a reasonable degree of price stability, and (c) provision of a minimum level of service to low income consumers. Third, power prices should help raise sufficient revenues to meet the financial requirements of the sector. Fourth, the power tariff structure must be simple enough to facilitate metering and billing customers. Finally, other economic and political requirements, such as incentive and penalty pricing schemes, subsidized electricity supply to certain sectors or geographic areas, also exist.

Since the above criteria are often in conflict with one another, it is necessary to accept certain trade-offs among them. The marginal cost approach to price-setting has both the analytical rigor and inherent flexibility to provide a tariff structure that is responsive to these basic objectives. In the first stage of calculating marginal costs, the economic (first-best) efficiency objectives of tariff-setting are satisfied because the method of calculation is based on future economic resource costs (rather than sunk costs) and also incorporates economic considerations such as shadow prices and externalities. The structuring of marginal costs permits an efficient and fair allocation of the tariff burden on consumers. In the second stage of developing marginal cost-based tariffs, deviations from strict marginal costs are considered in order to meet important financial and other social, economic (second-best), and political criteria. This second stage of adjusting strict marginal costs is generally as important as the first-stage calculation, especially in the DC context.

Any marginal cost-based tariff is a compromise among many different objectives. Therefore, there is no "ideal" tariff. By using the marginal cost approach, it is possible to revise and improve the tariff on a consistent and ongoing basis and thereby approach the optimal price over a period of several years, without subjecting long-standing consumers to "unfair" shocks in the form of large abrupt price changes.

Recent studies of the electric power sector in DCs indicate that electricity tariffs have not kept up with cost escalation (Munasinghe et al. 1988, Besant-Jones et al. 1990). Based on a survey of 60 developing countries, electricity tariffs on average declined between 1979 and 1988 from 5.21 cents/KWh to 3.79 cents/KWh in 1986 US constant dollars. The operating ratio (defined as the ratio of operating costs before debt service, depreciation and other financing charges, to operating revenue) for the almost 400 power utilities studied, deteriorated from 0.68 in the 1966 to 1973 period to 0.8 between 1980 and 1985. In some countries these deviations are significantly greater (Munasinghe 1991).

World Development Report 1992 emphasizes using taxes and regulations as an incentive for the energy industry and its consumers to adopt cleaner fuels and clean fuel technologies.

Recent advances in low cost metering and switching equipment have made it possible to consider (where appropriate), more sophisticated approaches to supply-demand balancing such as spot pricing and load control. In spite of the added costs of implementation of these schemes, potential savings to both the power producer and the consumer are often significant. Producers benefit by achieving some of their demand management objectives such as peak shaving and load shifting. Consumers benefit by being able to select service levels according to their individual needs and by a reduction in total cost.

Institutional and Regulatory Reform

Excessive government interference in organizational and operational matters has been a major problem in many parts of the developing world. This has adversely affected least-cost procurement and investment decisions, hampered attempts to raise prices to efficient levels, mandated low salaries tied to civil service levels, and promoted excessive staffing. This in turn has resulted in inadequate management, the loss of experienced staff due to uncompetitive employment conditions and poor job satisfaction, weak planning and demand forecasting, inefficient operation and maintenance, high losses, and poor financial monitoring, controls, and revenue collection. Incentives for utility managers to pursue technical efficiency and financial discipline, to consistently minimize production costs, and to provide reliable services, are lacking in DCs. Lack of internal funding, together with poor planning, operation, and maintenance practices has resulted in a wide-spread maintenance backlog and poor availability of generation capacity in DCs, thereby increasing the pressure for new generation. At the same time the cost of maintaining an existing plant is far less than the expense of building a new capacity.

Therefore, political decisionmakers, senior government officials, and ministry-level staff, should focus on critical macroeconomic and energy sector strategy and policy. The senior management of a power company, appropriately guided and buffered by an independent board of directors, would then conduct their daily operations free from government interference to meet the overall national policy objectives and targets within regulatory guidelines. As far as possible, the utility management should be assured of continuity at the top, even in the face of political changes. While the enterprise is provided wider autonomy, it would now become more accountable in terms of performance measured against an agreed set of specific objectives and monitored indicators.

Although delegation of authority to lower managerial levels can be extremely beneficial, staff training and education at all levels and stages of career would play a critical role in ensuring the success of such an approach.

The natural monopoly characteristics of some power enterprise functions, and necessity to manipulate these enterprises for general policy purposes, have been cited as reasons for maintaining large centralized public sector organizations. Nevertheless, given the observed problems inherent in stimulating management of these enterprises to be cost conscious, innovative, and responsive to consumer needs, there may be a need for more fundamental change. It could be worthwhile to trade off some of the perceived economies of scale in energy enterprises for other organizational structures which provide greater built-in incentives for management efficiency and responsiveness to consumers.

In particular, there appears to be considerable interest in the scope for more decentralization and greater private participation. DC power sector officials have been very active in studying such options, and some countries have already prepared the necessary legislative and institutional groundwork for this transition. In countries as diverse as Jordan and Malaysia, privatization initiatives have taken root, including divestiture of state-owned energy companies and encouragement of private power schemes.

India plans to install as much as 5000 MW of private power capacity over the 1990-95 period, and similar plans are underway in Indonesia, Malaysia, Thailand, and the Philippines. In Pakistan, the 1292 MW Hub Power Project is now under construction, with a further 2000 MW of private power in smaller plants currently under consideration. Jamaica is undertaking a BOT (Build-Operate-Transfer) power project. In Sri Lanka, a private company has been distributing power since the early 1980s and significant efficiency and service improvements have been observed during this period.

Options for private and cooperative ownership of energy enterprises could include both local and foreign participation as well as joint ventures. As long as a given regulatory framework prevails, it can be argued that the form of ownership (private and public) would not by itself affect operating efficiency. A first step towards decentralization could be for government-owned power enterprises to competitively contract out activities or functions better handled by others. Many companies already subcontract various construction-related activities. Some portions of the billing and collection process, or routine maintenance, can also be subcontracted. Among the advantages of such arrangements are lower costs and greater programming flexibility.

There are also opportunities for decentralization on a spatial basis. For example, larger countries may have independent regional power grids. Power distribution companies could be separate by municipality, with perhaps limited overlap in some fringe franchise areas, and have the right to purchase from various suppliers, when feasible. If private participation were allowed, one advantage might be that at least the large power consumers could also be legitimate shareholders who would be concerned not only with service efficiency, but also with the financial viability of the company.

Power generation also has potential for efficiency improvements through divestiture. While the bulk power transmission and distribution functions might be regarded as having more natural monopoly common-carrier type characteristics, this is not so with generation. In fact, there is substantial scope for competition in power generation with independent (perhaps foreign-owned enclave) producers selling to a central grid, as in the case of large industrial cogeneration. Free-standing generation companies would put up all or part of the capital and be paid only out of revenues from power sold at guaranteed prices. This would result in the desirable de-emphasis on large lumpy capital-intensive projects.

The case of Africa is an important exception to the above policy of decentralization. The problem in Africa is that electricity generation is too decentralized, and hence inefficient. Some measures to remedy this situation include: (1) modernizing and improving the efficiency of existing power systems; (2) developing and using local and regional primary energy for large-scale generation; (3) developing grid systems and encouraging regional interconnections; (4) recognizing the need for a national and regional master plan for electrification; and (5) putting into place sound energy policies, standards, and regulations that improve environmental aspects of energy use (Boutros 1991).

During the Cold War period, the power systems of the Eastern European nations were interconnected. Development plans for the system were coordinated by the Central Dispatching Organization (CDO), located in Prague. Many of the nations had plans to construct nuclear power plants. However, because of the persisting input capacity deficiencies and unreliable equipment, significant efforts are currently being made to enable connection to the 330,000 MWe Western European grid (UCPTE). Advantages to an East-West grid are outlined by Levai and Jazay: (1) a mutually advantageous energy exchange through improved electricity generation and utilization will be financially beneficial for both East and West. For example, the peak of an "all European" load can be reduced by 1.5 to 2.5 percent (or even 5 to 8 percent) due to the time zone differences between regions. Maximum consumption occurs at a different time in Eastern and Western European countries. Seasonal and daily fluctuations in energy demand may also increase availability of energy resources for both regions; (2) an integrated grid permits savings of 10-15 percent in spinning reserves, generating capacity, compared with the total reserve required when the two systems operate independently; and (3) it would be easier to provide mutual assistance in emergencies (Levai and Jaszay 1991).

SED Options Matrix

The summary in Table 6 shows the impacts of the various options on the three elements of sustainable development. While, efficient supply side options (that is, reductions in T&D losses), have clear economic gains in terms of savings in capital investments and environmental benefits from reductions in greenhouse emissions that result from increased electricity

Table 6

SED Options Matrix

Option	Impact		
	Economic	**Environmental**	**Social**
Supply Efficiency	+	+	
End-Use Efficiency	+	+	+
Advanced Technologies	-	+	+
Renewables	-	+	+
Pricing Policy	+	+	+/-
Privatization/Decentralization	+	+/-	+/-

supply, they do not have obvious social benefits. Efficient end-use options as shown in the case of an efficient fuelwood stove have benefits relating to all three elements. Although advanced technologies such as clean coal combustion technologies are essential for reducing air pollutants such as CO_2 and NO_x that cause respiratory diseases and reduce productivity, many developing countries cannot afford such high cost technologies. Likewise renewable energy sources also provide environmental and social benefits by reducing a country's dependence on traditional fossil fuels. However, in terms of generating costs renewables are more expensive than fossil fuels.

5 Sustainable Energy Development: A Case Study of Sri Lanka

An MCA based approach was used by Meier and Munasinghe (1994) in a study of Sri Lanka. The objective was to demonstrate how environmental externalities could be incorporated into power system planning in a systematic and efficient manner. Sri Lanka presently depends largely on hydro power for electricity generation. However, if increased demand is to be met over the next decade, there seems little choice other than to begin building large coal- or oil-fired stations, or to build hydro plants whose economic returns and environmental impacts are increasingly unfavorable. In addition, there are a wide range of other options (such as wind power, increasing use of demand side management, and system efficiency improvements), that make decisionmaking quite difficult— even in the absence of the environmental concerns. The study is relatively unique in its focus on these kinds of 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.

Environmental Issues

Sri Lanka is one of the more densely populated countries of the world, and land availability is an important issue. In general, hydro plants are in the wet zone areas where there is little vacant land nearby for resettled inhabitants to relocate, while land that is available at greater distances is often seen by potential evacuees as undesirable because of questions concerning the availability of adequate water supply. A rough but effective way of comparing the likely extent of potential land-related environmental impacts across projects is the area inundated per KWh of capacity. This varies between zero and as much as 150 hectares per KWh. The correlation between the installed capacity and the amount of land to be inundated is poor; large projects do not necessarily mean worse environmental impacts and vice versa.

The progressive loss of Sri Lanka's natural forests over the past fifty years is well documented, and is one of the country's most important environmental concerns. Power sector projects will be scrutinized very carefully for their potential impact on what natural forest areas remain, even if it is true that the power sector per se has been a relatively minor contributor to the loss of forest lands. The main reason for deforestation in the past has been planned agricultural development and settlement schemes, chena cultivation, encroachment by unplanned settlement and cropping, illicit logging and uncontrolled fuelwood and timber extraction.

Relatively little is known about ambient air quality in Sri Lanka. In most parts of the country the air quality is fairly good, a reflection of the limited extent of industrialization except in Colombo, and the natural ventilation provided by strong monsoon winds. In Colombo, however, the sharp increase in automobile and bus traffic over the past decade has led to strong indications of increasing deterioration of air quality. Nevertheless, based upon what we do know about patterns of energy utilization certain inferences can be drawn. It is fairly certain that at present the power sector contributes only marginally to air pollution in Sri Lanka. However, this is expected to change significantly once the anticipated coal burning power plants are added to the system beginning in the late 1990s. Acid rain is likely to become an increasingly important environmental issue in the Asia-Pacific region given the fact that the energy plans in many countries, in particular India and China, call for rapid development of fossil energy systems.

Acid rain is largely a long-range phenomenon, and it is fairly obvious that the extent to which acid rain is or will be experienced in Sri Lanka is as much a function of emission trends of acid rain precursors in India as in Sri Lanka itself.

Global warming and transnational acid rain are conceptually different from local environmental impacts, since in the former case the impacts will occur predominantly in other countries. If the main economic objective is to maximize welfare in Sri Lanka, decisionmakers in Sri Lanka would be unwilling to incur additional costs if the benefits of such actions accrue mainly to other nations. In this case study, it is assumed that Sri Lanka will be reimbursed by the international community for the incremental costs of global warming mitigation efforts, or that the Government would have signed an international agreement committing itself to undertake certain carbon dioxide emission reduction measures.

Because Sri Lanka is a small island (65,000 square kilometers), which has been isolated for relatively long periods, there are a large number of endemic species. Among Asian countries, Sri Lanka has the highest level of biological diversity. The NSF Committee on Research Priorities in Tropical Biology identifies Sri Lanka as demanding special attention. Biological diversity is under threat in Sri Lanka primarily from the progressive reduction in its natural forests and other natural habitats, especially through the selective exploitation of tree species, particularly for timber. Therefore, the power sector is likely to come under intense scrutiny from this perspective.

As the generation mix shifts from one that is predominantly hydro to one in which large base load fossil fueled plants play an increasing role, it is inevitable that sites will need to be found on the coast to accommodate such thermal plants. The economic importance of preventing environmental degradation in the coastal zones is well established. Foreign tourism, an important source of foreign exchange, is largely focused on the country's sandy beaches and coastal estuaries and lagoons. The marine fishery industry provides employment to some 100,000 persons, and is the largest source of animal protein for Sri Lanka. The main environmental issue concerns the discharge of heated effluents into waters of the coastal zone, where there exist numerous ecosystems that are extremely sensitive to temperature increases, including (1) coral reefs, sea grass beds, benthic communities, mangrove stands, rocky and other shores; (2) zooplankton and phytoplankton communities which are free floating; and (3) nursery grounds for fish and prawns.

Methodology

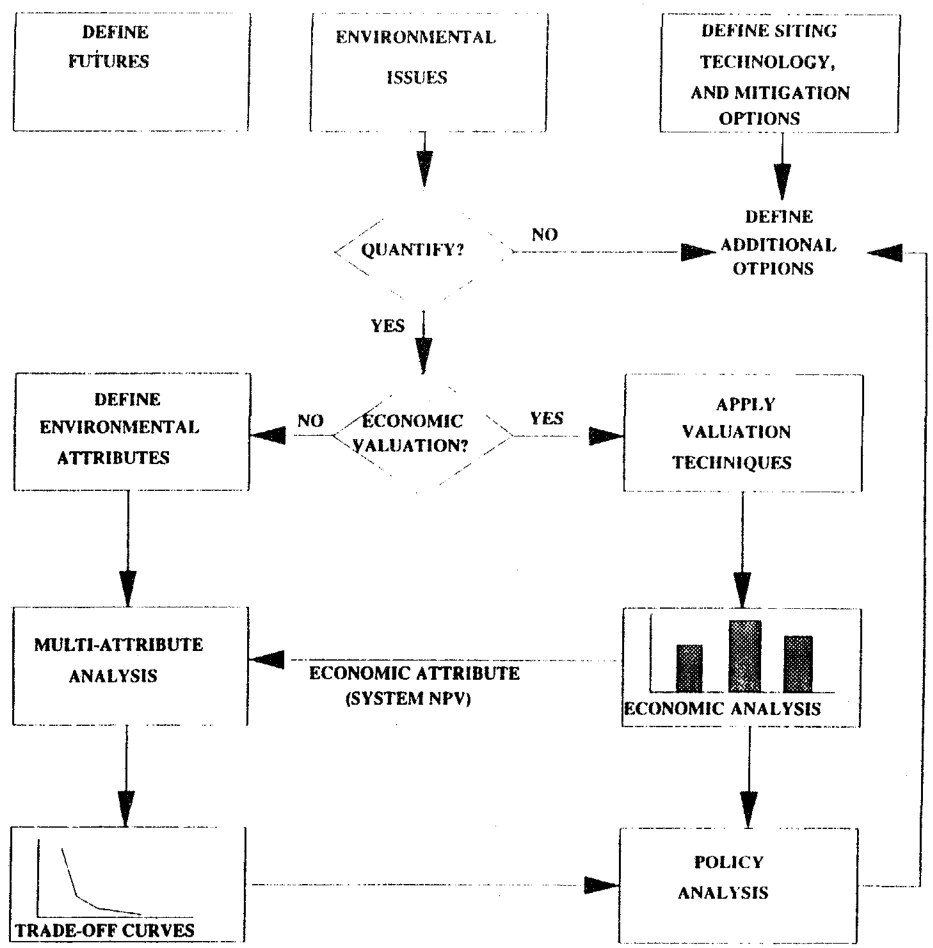
Multi-criteria analysis has been developed expressly for situations where decisions must be made taking into consideration more than one objective which cannot be reduced to a single dimension. Its central focus is the quantification, display and resolution of trade-offs that must be made when objectives conflict. In the case of application to the power sector, there may well be strategies that have beneficial impacts on both environmental and economic objectives--most energy-efficient investments that are economically justifiable also bring about a reduction in emissions and hence improve environmental quality as well as economic efficiency. But most options require that trade-offs must be made: wind plants, for example, potentially provide substantial environmental benefits but are more expensive than other options.

The overall methodology is illustrated in Figure 6, and involves the following steps:

(1)The definition of the options to be examined.

Figure 6

General Methodology for Environmental Analysis of Power Systems



Source: Meier and Munasinghe 1994.

(2)The selection and definition of the attributes, selected to reflect planning objectives.

(3)The 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 cost attribute.

(4)The quantification of those attributes for which explicit economic valuation is inappropriate, but for which suitable quantitative impact scales can be defined.

(5)The translation of attribute value levels into value functions (known as "scaling").

(6)The display of the trade-off space, to facilitate understanding of the trade-offs to be made in decisionmaking.

(7)The definition of a candidate list of options for further study: this also involves the important step of eliminating from further consideration options that are clearly inferior.

In some applications it may be appropriate to add two further steps: the definition of weights for each attribute, and the application of an amalgamation rule to provide a single overall ranking of options. However, the Sri Lanka case study did not follow this approach.

Application to the Sri Lanka Power Sector

Policy option definition: A variety of options were selected for study, including a whole range of siting, pollution control mitigation and technology options. Indeed, it is very important that as few a priori judgments as possible are made about the "feasibility" or "practicality" of options, because for the analysis to be useful, meaningful trade-offs must be examined. For example, in the case of the Trincomalee coal-fired power plant (on the northeast coast), the environmental impact assessment prepared in the mid-1980s considered only a very narrow range of options: all alternatives studied involved sites on Trincomalee Bay, with once-through cooling to a shallow bay inlet. Other south coast sites had been eliminated earlier on grounds of high cost (because these sites could not accommodate large coal transport vessels, resulting in higher transport costs). Yet the additional costs of an evaporative cooling system, or of an outfall system that would discharge heated effluents to the deeper parts of the Trincomalee Bay, proved to be less than the incremental coal transport costs to a site on the south coast.

The main set of policy options examined, beyond variations in the mix of hydro and thermal plants, included (1) demand side management (using the illustrative example of compact fluorescent lighting); (2) renewable energy options (using the illustrative technology of wind generation); (3) improvements in system efficiency (using more ambitious targets for transmission and distribution losses than the base case assumption of 12 percent by 1997); (4) clean coal technology (using pressurized fluidized bed combustion (PFBC) in a combined cycle mode as the illustrative technology); and (5) pollution control technology options (illustrated by a variety of fuel switching and pollution control options such as using imported low sulfur oil for diesels, and fitting coal-burning power plants with flue gas desulfurization (FGD) systems).

Attribute selection: Great care needs to be exercised in criteria or attribute selection— they should reflect issues of national (as opposed to local project-level) significance, and ought to be limited in number. There is little gain from a proliferation of attributes. Increasing the number of attributes is not a substitute for assigning proper weights to environmental attributes in the decision process. On the contrary, the more attributes considered the more complex the analysis, and the higher the probability that the results will be hard to interpret and decisionmakers will not find the exercise useful. It often occurs that, in a desire to be comprehensive, there is an inclusion of all possible impacts, making it more difficult to demonstrate trade-offs, and possibly introducing biases through a reluctance to assign low weighting to attributes.

The following environmental criteria or attributes were used in the study. To capture the potential impact on global warming, carbon dioxide emissions were defined as the appropriate proxy. To be sure, the relationship between global carbon dioxide concentrations and the actual physical impacts that may follow, such as sea level rise or changes in monsoonal rainfall patterns are still poorly understood, and in any event, unlikely to be captured by simple linear correlations. However, since Sri Lanka's contribution to worldwide emissions will remain extremely small, the assumption of linearity of impacts (relative to global carbon dioxide emissions) is not unreasonable.

To capture health impacts, use was made of the population-weighted increment in fine particulates and nitrogen oxides attributable to each source. To this end a simple Gaussian plume model was applied to all of the major sites; incremental ambient concentrations for 1 km square cells were calculated to within a 20 km radius, and then multiplied by the population in each cell.

To capture other potential air pollution impacts, such as acid rain, emissions of sulfur dioxide and nitrogen oxides were used. As an illustrative social impact, the study used the creation of labor opportunities. Employment creation is an important objective of national policy, and in Sri Lanka there has occurred frequent discussion of the need for employment creation in the south where youth unemployment rates are especially high. It should be noted that what is captured in this attribute is the separate and purely political objective of employment creation, and is to be distinguished from strictly economic benefits that would be captured by the use of shadow wage rates appropriate to reflect high unemployment in the construction cost estimates. All of these impacts were appropriately discounted and expressed as a present value. Finally, to capture the potential biodiversity impacts, a probabilistic index was derived (as discussed below).

Attribute quantification: The problems of quantification are well illustrated in the case of the biodiversity attribute. At the planning level, detailed site specific information at the potential power plant sites is unlikely to be available. Consequently the only quantification that appears possible is to derive a probabilistic index that gives the decisionmaker information about the likelihood that the detailed environmental impact statement will reveal the presence of an endemic species, significantly impact ecosystems of high biological diversity, or affect a habitat already in a marginal condition.

There are a number of practical problems in deriving an appropriate index. The first is that the value of the area lost is a function of what remains of the habitat. For example, the loss of the last hectare of an ecosystem would be unacceptable, whereas the loss of one hectare if 1,000 hectares remain would be much less. Second, ecosystems may require a minimum area for long-term survival, which implies that the value function would need to tend to infinity as it approaches that minimum value. Perhaps even more importantly, the argument is sometimes made that the value to be ascribed to the loss of habitat associated with some regulatory or governmental decision depends on whether it remains secure.

Some impacts, however, resist direct quantification, even in terms of the sort of probabilistic scale derived for biodiversity. For example, the quantification of potential damages to aquatic ecosystems from thermal discharges is extremely problematic, in large part because of the difficulties in extrapolating from one ecosystem to the other. The general effects of thermal discharges into coastal waters are of course well known. Discharges into the well-mixed, surface layer would usually have the general tendency to repel fish. On the other hand, if the discharge is below the thermocline, thermal discharges would have a generally beneficial effect, as the up-welling effect caused by plume buoyancy brings nutrients to the layers near the surface. Still, attaching specific numerical estimates to the values of this general function is essentially impossible. What can be done as a generic calculation that can be used to compare different sites is to begin with a definition of what is considered to constitute an acceptable environmental risk; for example, say a temperature increase of no more than 1 degree centigrade at the surface. The surface area over which this criterion is exceeded is then calculated as a function of the cooling system design proposed.

Some Illustrative Results

With options and attribute definitions in hand, the case study then generated the multi-dimensional trade-off space. Using the ENVIROPLAN model, the attribute values for each of the environmental attributes, and the cost attribute (for which average incremental cost over a twenty year planning horizon was used) were calculated for every option, with results displayed as a series of two-dimensional trade-off curves. In a final step, the list of candidate plans for further study was then derived by examining dominance relationships among all criteria simultaneously.

Figure 7 illustrates a typical trade-off curve, in this case for health impacts. The "best" solutions are those that lie closest to the origin, and the so-called trade-off curve, defined by the set of "non-inferior" solutions, represents the set of options that are superior, regardless of the weights assigned to the different objectives. For example, on this curve, the option defined as "iresid", which calls for the use of low sulfur imported fuel oil at diesel plants is better on both the cost and the environmental objective than the use of flue gas desulfurization systems (identified as the point "FGD").

A quite different trade-off curve was derived for biodiversity, and on Figure 8 is illustrated the trade-off between biodiversity index value and average incremental cost. Most of the options have an index value that falls in the range of 50 to 100: the no hydro option has an essentially zero value, because the thermal projects that replace hydro plants in this option tend to lie at sites of poor biodiversity value (either close to load centers or on the coast). For example, while wind plants would require rather large land area, the vegetation of the area on the south coast has relatively low biodiversity value, and therefore the overall increase in biodiversity impact of this option is small. Thus, the best options (or non-inferior curve) includes the no hydro option, and run-of-river hydro options that require essentially zero inundation. Note the extreme outliner at the top right hand corner, which is the Kukule hydro dam— it has a biodiversity loss index (B=530) that is an order of magnitude larger than for other options (B=50 to 70).

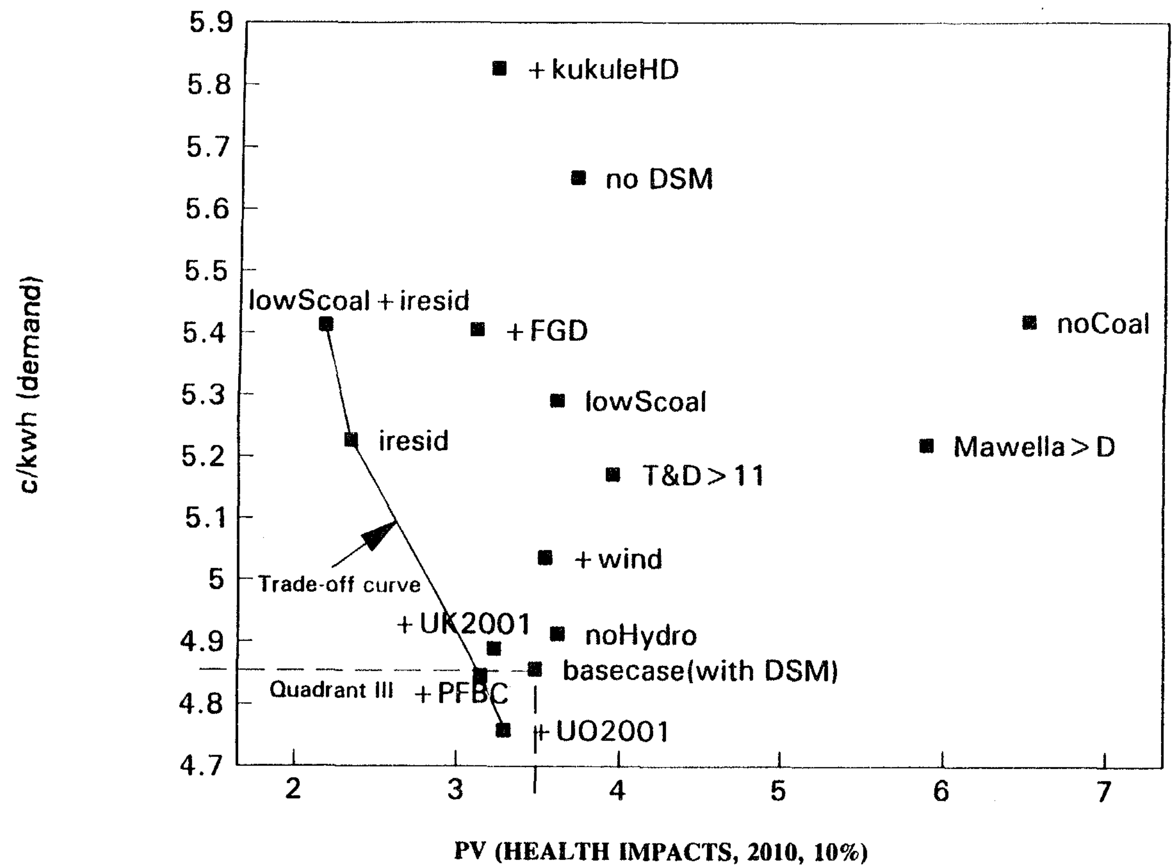
The case study drew several useful conclusions. The first four listed below are of a methodological nature, and deal with the extent to which multi-attribute methods are potentially effective in assisting decisionmakers. The remaining ones deal with the substantive policy recommendations whose focus is to ensure that environmental considerations are appropriately incorporated in the planning process.

First, the results of the case study 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 decisionmakers. For example, the study determined that the value of human life necessary to justify flue gas desulfurization at potential sites for coal-fired power plants was on the

Figure 7

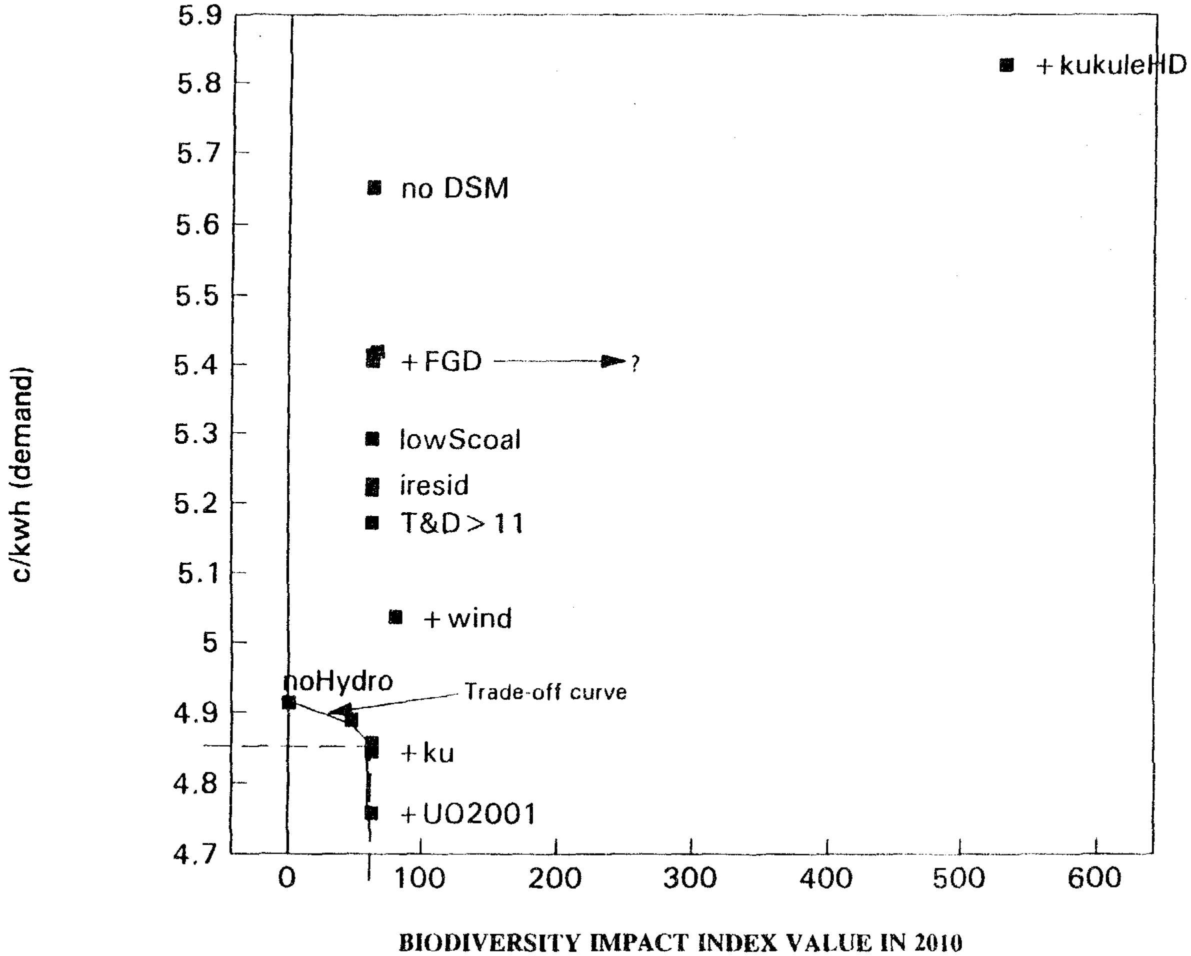
Cost Versus Health Impacts



Source: Meier and Munasinghe 1994.

Figure 8

Cost Versus Biodiversity Impacts



Source: Meier and Munasinghe 1994.

order of $1.5 million. This is at least one (if not two) orders of magnitude greater than what would be needed to justify the installation of modern diagnostic equipment at the regional hospitals.

Third, the case study indicated that certain options were in fact clearly inferior, or clearly superior, to all other options when one examines all impacts simultaneously. For example, the high dam version of the Kukule hydro project can be safely excluded from all further consideration as a result of poor performance on all attribute scales (including the economic one). On the other hand, implementation of certain demand side management measures dominates all other options; that is, they yield positive gains in terms of economic and environmental criteria.

Fourth, the results indicate that it is possible to derive attribute scales that can be useful proxies for impacts that may be difficult to value. For example, use of the population-weighted incremental ambient air pollution scale as a proxy for health impacts permitted a number of important conclusions that are independent of the specific economic value assigned to health effects. Thus, the study clearly demonstrated that if the health effects of pollutants associated with fossil fuel combustion (particularly fine particulates and nitrogen oxides) are to be considered, then the most effective strategy for reducing the overall population dose is to install tighter pollution controls at oil-burning power plants located in or near urban areas, rather than installing FGD systems at the more remote sites suitable for coal-burning power plants.

Finally, with respect to the practical implications for planning, the study came to a series of specific recommendations on priority options, including (1) the need to systematically examine demand side management options, especially fluorescent lighting; (2) the need to examine whether the present transmission and distribution loss reduction target of 12 percent ought to be further reduced; (3) the need to examine the possibilities of pressurized fluidized bed combustion (PFBC) technology for coal power; (4) replacement of some coal-fired power plants (on the south coast) by diesel units; and (5) the need to re-examine cooling system options for coal plants.

6 Conclusions

Increasing levels of energy-related environmental degradation in both industrialized and developing countries have led to a recognition of the need for improved energy options for sustainable development. The primary objective is to maximize net economic welfare of energy development while maintaining the stock of economic, ecological and sociocultural assets for future generations and providing a safety net to meet basic needs and protect the poor. Sustainable energy options may be identified using a comprehensive and integrated framework for analysis and decisionmaking that takes into account multiple actors, multiple criteria, multilevel decisionmaking and many impediments and constraints. In the past, the principle planning objective of energy development has been to meet the anticipated needs at least economic cost. Now, environmental and social concerns also must be incorporated early at the regional and sectoral planning stages in order to ensure sustainable energy development. However, difficulties in valuing certain environmental and social impacts of energy development and the large number of options, may require techniques of multi-criteria analysis (MCA), rather than conventional cost-benefit analysis (CBA) methods, to provide a range of feasible alternatives as opposed to one best solution. Using MCA, "win-win" energy options that satisfy all three elements of sustainable development (that is, economic, environmental and social) may be identified and after having done so, trade-offs can be made from other available sustainable energy options. A case study of the Sri Lankan power sector demonstrates this approach of MCA may improve decisionmaking.

Dealing with energy-related environmental and social issues will require increased cooperation between industrialized countries and developing countries. Developing countries have limited capabilities to address global environmental concerns. Without enhanced flows of incremental technical and financial resources from industrialized countries, positive prospects for energy development that will move the world towards a more sustainable development path will be hampered.

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