

The Allama Iqbal Lecture

**Sustainable Energy Development (SED)—
New Path for Pakistan**

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1. BASIC FRAMEWORK

1.1. Background

Following the 1992 Earth Summit in Rio de Janeiro, the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg, and the 2012 Rio+20 Earth Summit in Rio de Janeiro, sustainable development has become a widely accepted concept. World decision makers are seeking a more sustainable development path through the ongoing UN Post-2015 Agenda discussions, which includes key themes like the Green Economy (GE) and the Sustainable Development Goals (SDG). They are hoping to find integrated solutions to many critical problems, including traditional development issues (such as energy scarcity, economic stagnation, poverty, hunger, and illness), as well as newer challenges (like climate change and globalisation).

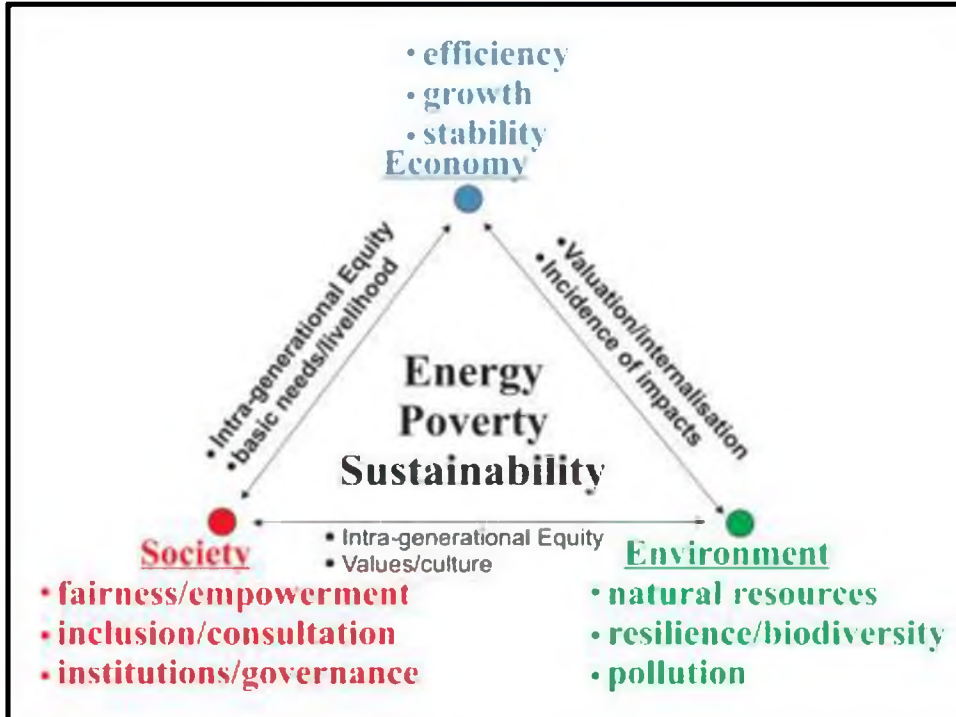
Energy is critical for sustainable development. Sustainable energy development (SED) is an operational framework involving the harnessing of energy resources for human use, in a manner that supports lasting development [Munasinghe (1995)]. We begin with a review of sustainable development itself, before describing the key role of energy. The World Commission on Environment and Development originally defined it as “development which meets the needs of the present, without compromising the ability of future generations to meet their own needs”, and there have been many subsequent re-definitions.

Given the lack of an operational approach or practical framework that attempts to define, analyse, and implement sustainable development, Munasinghe first proposed the Sustainomics framework at the 1992 Rio Earth Summit, as “a transdisciplinary, integrative, comprehensive, balanced, heuristic and practical meta-framework for making development more sustainable” [Munasinghe (1992, 2002, 2010)]. One key element of this approach is the widely-accepted sustainable development triangle shown in Figure 1. It encompasses three major perspectives—economic, social and environmental. Each viewpoint corresponds to a domain (and system) that has its own distinct driving forces and objectives. The economy is geared towards improving human welfare, primarily through increases in consumption of goods and services. The environmental domain

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focuses on protection of the integrity and resilience of ecological systems. The social domain emphasises enrichment of human relationships, achievement of individual and group aspirations, and strengthening of values and institutions.

Fig. 1. Sustainable Development Triangle—Harmonising Economic, Social and Environmental Dimensions



Source: Munasinghe (1992).

Meanwhile, energy has emerged as a key resource, which interacts critically with the economic, social and environmental dimensions of sustainable development. First, it has long been perceived as a major driving force underlying economic progress, and in turn, economic growth itself further stimulates energy demand. Second, energy production and use are strongly interlinked with the environment. Third, energy is a basic human need, which significantly affects poverty and social well-being. Recently, growing energy demand has also become associated with global climate change—posing an unprecedented challenge to humanity. The wide-ranging inter-linkages between energy and sustainable development are analysed in this article, especially the role of renewable energy.

1.2. Risks to Current Development Prospects

The world is currently facing multiple economic, social, and environmental threats, which can interact catastrophically, unless they are addressed urgently and in an integrated fashion—by making development more sustainable [Munasinghe (2009)]. Piecemeal responses have proved to be ineffective, since the problems are interlinked. Sustainable Energy Development (SED) is a key part of the solution.

Economic, Social and Environmental Threats

The economic collapse is the most urgent and visible global problem (Figure 2). An asset “bubble” driven by investor greed rapidly inflated the value of financial instruments well beyond the true value of the underlying economic resource base. The collapse of this bubble in 2008 caused the global recession [OECD (2009) and Taylor (2009)].



Source: Author.

Major social problems of poverty and inequity are also shown in Figure 2, which continue to undermine the benefits of recent economic growth, excluding billions of poor from access to productive resources and basic necessities [World Bank (2009)]. In 2000, the top 20 percentile of the world’s population by income, consumed 60 times more than the poorest 20 percentile [Munasinghe (2010)]. Economic recession now exacerbates poverty, worsening unemployment and access to survival needs.

Finally, mankind faces major environmental problems, because myopic economic activities continue to severely damage the natural resource base on which human well-being ultimately depends [MA (2005); UNEP (2008); UNEP (2011)]. Climate change is one major global outcome, but equally serious issues are the degradation of local water, air, and land resources. It is a potent risk multiplier, systematically worsening the other crises described earlier. Ironically, the worst impacts of climate change will fall on the poor, who are not responsible for the problem [IPCC (2007)].

Unfortunately, our current policy priorities are inadequate to face these challenges. Governments very quickly found over six trillion dollars for stimulus packages to bail out rich banks and boost consumption [G20 (2009)]. However, only about 100 billion dollars per year are devoted to poverty reduction, and far less to combat climate change [World Bank (2009)]. Annual military expenditures at almost \$2 trillion are 20 times larger than development aid. The asset bubble (over \$100 trillion) far exceeded annual global GDP (\$60 trillion), while the high share of trade (>30 percent) in GDP underlines global connectivity that increases systemic risk. Furthermore, the recession has dampened enthusiasm to address more serious sustainable development issues.

1.3. Elements of Sustainomics

In the sustainomics framework, sustainable development is described as a process for improving the range of opportunities that will enable individual human beings and

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

Decision makers are invariably pre-occupied with immediate problems like growth, poverty, food security, unemployment, and inflation. The best method of seizing their attention is to pursue an integrated approach that addresses all these issues within a broad national sustainable development strategy. Economic analysis has a special role in national policy making, since many important decisions are economic ones. The practical and holistic Sustainomics framework (Box 1) seeks to overcome the shortcomings of mainstream (neoclassical) economic policy-making, which often ignores many crucial environmental and social aspects.

Box 1.

Principles of Sustainomics

First, making development more sustainable (MDMS) becomes the main goal. It is a step-by-step method that empowers people to take immediate action, which is more practical because many unsustainable activities are easy to recognise and eliminate—like conserving energy. While implementing such incremental measures, we also continue parallel efforts to achieve long term sustainable development goals. One key test for potential climate policies would be whether they would make development more (or less) sustainable.

Second, policy issues need balanced and integrated analysis from three main perspectives: social, economic and environmental (described earlier in Figure 1). Interactions among these three domains are also important.

Third, we need to transcend conventional boundaries imposed by values, discipline, space, time, stakeholder viewpoints, and values. It is essential to replace unsustainable values like greed and selfishness with sound ethical principles including altruism and enlightened self-interest—this is a longer term task involving education, communication and leadership, especially focusing on the young. Trans-disciplinary analysis is needed to find innovative solutions to complex problems of sustainable development and climate change that cut across conventional disciplines. Spatial analysis must range from the local to the global—typically from the community to the trans-boundary river basin and planetary scales. The time horizon needs to extend to decades or centuries. Cross-stakeholder data sharing, transparency and cooperation (especially civil society and business working with government) need to be strengthened, by promoting inclusion, empowerment and participation.

Finally, the sustainomics framework uses a variety of practical full cycle tools—both new methods and conventional ones. They are applied innovatively to encompass the full operational cycle from initial data gathering to practical policy implementation, monitoring and feedback. Munasinghe (2002, 2010) describes practical tools of sustainomics at the global and national levels, including integrated assessment models (IAMS), macro- and sectoral-modelling, environmentally adjusted national income accounts (SEEA), poverty analysis, and the Action Impact Matrix (AIM). At the project level, other useful methods for sustainable development analysis (SDA) are cost-benefit analysis (CBA), multicriteria analysis (MCA), environmental and social assessment (EA, SA), and economic valuation of environmental and social impacts. At all levels, the choice of appropriate sustainable development indicators is also vital, derived from the basic economic-social-environmental metric (UNCSD 2007). The range of policy instruments includes both economic methods (like pricing, taxes and charges, tradable permits, investments and financial incentives), and non-economic ones (like regulations and standards, quantity controls, voluntary agreements, information dissemination, and research and development).

In general, sustainomics leads to the following solutions. First, wastes ought to be generated at rates within the assimilative capacity of the environment. Second, scarce renewable resources should be utilised at rates below the natural rate of regeneration. Third, non-renewable resource use rates should depend on the substitutability between these resources and technological progress. Both wastes and natural resource inputs might be reduced, by moving from linear throughput to closed loop (or recycling) mode. Finally, inter- and intra-generational equity, and poverty alleviation, pluralistic and inclusive decision making, and enhanced social values and institutions, are important additional considerations.

2. SUSTAINABLE ENERGY DEVELOPMENT (SED)

2.1. Linkages between Energy Use and Sustainable Development

Energy-economy Linkages

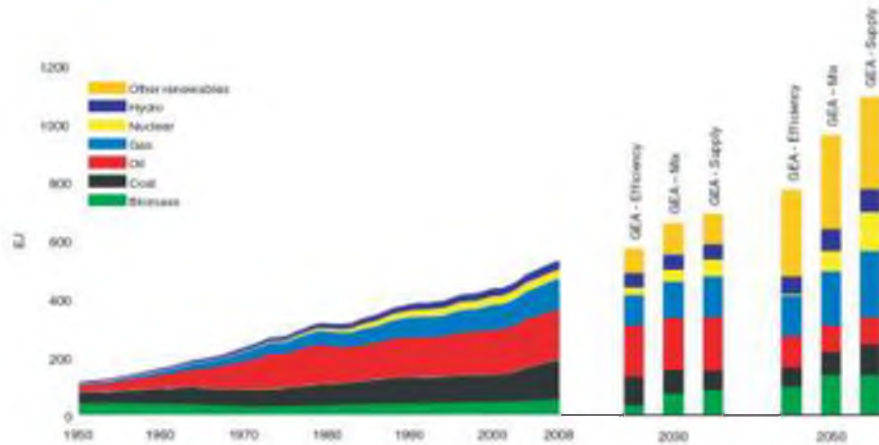
Energy has become a driving force for modern economies, with extensive use of commercial energy. Figure 3 shows that past energy supply has been dominated by fossil fuels like oil, natural gas and coal, while the share of renewable energy is expected to increase sharply from 17 percent in 2009 to 30-75 percent of total primary energy by 2050—in various future growth scenarios [GEA (2012)]. The main renewable sources in 2009 were traditional biomass and hydropower (Figure 4), but new renewables (like wind, solar, geothermal, and ocean energy) will dominate in 2050, since their technical potential is much greater (Figure 5) and relative costs will fall. An estimated US\$260-1120 billion per year will need to be invested in renewables to achieve 2050 targets.

Technological progress and efficiency improvements have reduced the energy intensity of economic production (i.e., lower requirements of physical energy per unit of economic output). Electricity will continue to play an increasingly important role, as a safe, clean and convenient form of energy.

Energy-Environment-Society Linkages

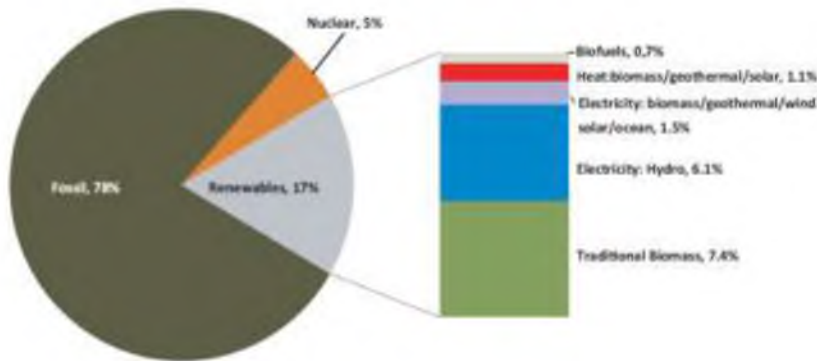
The environmental and social implications of energy use have not been as well analysed as energy-economy linkages. Complete life-cycle analyses of the mining, refining, processing, transport, conversion and transformation of various fuels like oil, coal and nuclear materials, all show significant impacts. While electricity has relatively few environmental and health consequences at the point of end use, key environmental and social issues arise from power generation, depending on the energy sources. Oil- and coal-fired plants not only have national impacts but also regional and global environmental and health effects. Even renewable energy sources, which are perceived to be “clean,” have some negative social and environmental impacts. Yet, access to affordable energy (especially electricity), yields substantial social benefits, often transforming the quality of life of poor households.

Fig. 3. Growth of World Primary Energy by Source 1950-2008, and Three Future Scenarios Developed by the Global Energy Assessment (GEA).



Source: GEA (2012).

Fig. 4. 2009 Shares of Energy Sources in Total Primary Energy—Renewables Provide 17 percent, Mainly Biomass and Hydroelectricity



Source: GEA (2012).

Fig. 5. Renewable Energy: Global Utilisation in 2005 and Technical Potential (Exajoules/Year)

Utilisation 2005 [EJ]	Technical Potential [EJ/yr]	
46.3	160–270	Biomass, MSW, etc.
2.3	810–1545	Geothermal
11.7	50–60	Hydro
0.5	62,000–280,000	Solar
1.3	1250–2250	Wind
–	3240–10,500	Ocean

Source: GEA (2012).

Transnational Issues

Acid deposition is perhaps the most serious of the transnational issues faced today. It is caused by oxides of sulphur 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 sulphur dioxide and nitrogen oxides into the atmosphere. The transport of sulphur dioxide occurs over distances more than 1000 km, across national boundaries. Acid depositions caused by sulphur and nitrogen oxides result in damage to trees and crops, and sometimes extend to acidification and destruction of aquatic ecosystems like streams and lakes. They also lead to the corrosion, erosion, and discoloration of buildings, monuments and bridges. Indirect health effects are caused by the mobilisation of heavy metals in acidified water and soil. Other important transnational issues include environmental and health impacts of radiation due to severe nuclear accidents, oceanic and coastal pollution due to oil spills, downstream siltation of river water in one nation due to deforestation of water sheds and soil erosion in a neighbouring country, and changes in hydrological flow and water conditions caused by dams.

Global Issues

The Intergovernmental Panel on Climate Change [IPCC (2007)] has identified that energy use is the major contributor to anthropogenic greenhouse gas (GHG) emissions—mainly CO₂ and other gases like N₂O, CH₄ and CFCs that will lead to climate change and undermine sustainable development prospects. First, global warming poses a significant potential threat to the future economic well-being of the majority of human beings. Second, climate change will harm the poorest groups disproportionately, undermining social welfare and equity. Third, from the environmental viewpoint increasing anthropogenic emissions and accumulations of GHGs will significantly perturb a major global subsystem—the atmosphere. Climate change will also threaten the stability of a range of critical, interlinked physical, ecological and social systems and subsystems.

2.2. Framework for SED

Sustainable development is the broad rationale underlying most national level planning and policy-making. Ideally, power and energy planning must also be part of and closely integrated with overall sustainable development strategies, to meet many interrelated and frequently conflicting national objectives. Specific goals for sustainable energy development might include: (a) ensuring economic efficiency in energy supply and use to maximise growth, including energy efficiency; (b) raising sufficient revenues from energy sales, to finance sector development; (c) socioeconomic concerns, like meeting basic energy needs of the poor, or developing special regions (particularly rural or remote areas) and priority sectors of the economy; (d) preserving the environment; (e) diversifying supply, reducing dependence on foreign sources, saving scarce foreign exchange, and meeting national security requirements; (f) price stability; etc.

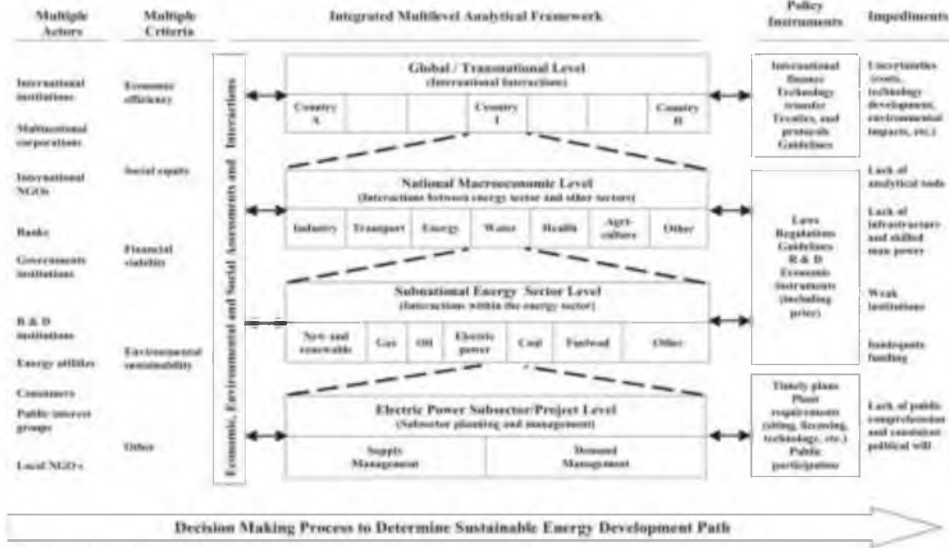
Integrated Approach

Successful planning and implementation of national energy programmes must explicitly link the energy sector to sustainable development of other parts of the

economy. An integrated approach will help decision-makers to formulate policies and provide market signals and information to economic agents that encourage more efficient and sustainable energy production and use, as shown in Figure 6a.

The middle column shows the core—a framework for integrated, hierarchical, multilevel analysis and integrated national energy planning (INEP) [Munasinghe (1988)]. The top level of SED recognises transnational linkages. Thus individual countries are embedded in an international matrix, and global economic, social and environmental conditions impose exogenous inputs or constraints on national decision-makers.

Fig. 6a. Sustainable Energy Development (SED) Framework



Source: Munasinghe (2010).

The second hierarchical level in the figure focuses on the multi-sectoral national economy, of which the energy sector is a part. Thus, energy planning requires analysis of links between the energy sector and other sectors, including energy needs of user sectors (like industry, transport, and agriculture), input requirements of the energy sector, and impacts of energy supply and pricing policies.

The next level of SED disaggregates the energy sector into sub-sectors such as electricity, petroleum products, coal etc. This permits detailed analysis, with special emphasis on interactions among different energy sub-sectors, substitution possibilities, and resolution of policy conflicts.

The lowest hierarchical level pertains to energy analysis within each energy sub-sector, where line institutions (both public and private) carry out detailed energy resource evaluation, planning and implementation of projects—including sustainability assessments.

In practice, the various levels of SED merge and overlap considerably, requiring careful study of (inter) sectoral linkages. Energy-social-environmental interactions (represented by the vertical bar) cut across all levels, and provide important paths for incorporating environmental and social considerations into national energy policies.

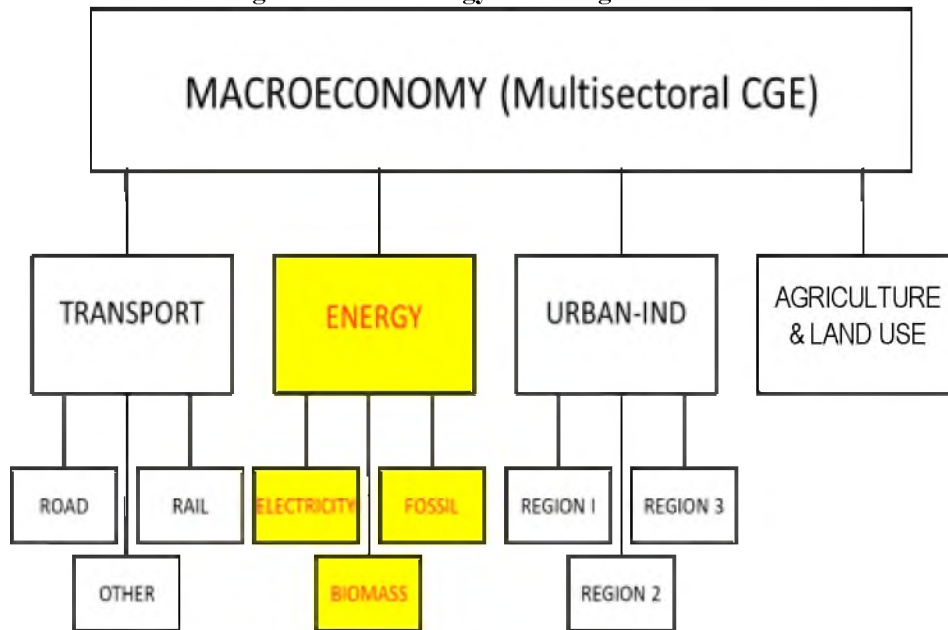
SED facilitates policy-making and does not imply rigid centralised planning. The process results in the development of a flexible and constantly updated sustainable energy strategy designed to meet national goals. This strategy (of which the investment programme and pricing policy are important elements), may be implemented through energy supply and demand management policies and programmes that make effective use of decentralised market forces and incentives.

In particular, SED implies improvements in overall economic efficiency through better energy management. Figure 6a shows various policy instruments available to decision-makers for implementing sound energy management. While formulating policy, one must consider the interests of multiple government, business and civil society stakeholders, ranging from international institutions to local energy users. This figure also indicates the most important impediments that limit the effectiveness of policies.

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

A macro-energy modelling framework is needed to implement this approach—a typical example is shown in Figure 6b. A computable general equilibrium (CGE) multi-sector macroeconomic model links the energy supply and user sectors and shows impacts of broad macro-policies. The energy sector itself is disaggregated into different energy types, facilitating analysis of energy subsector interactions. Finally, each subsector is studied in detail using specialised submodels—e.g., the electric power sector is modelled in detail using a long term power system expansion planning model.

Fig. 6b. Macro-energy Modelling Framework



Source: Munasinghe (2010).

Identifying Sustainable Energy Options: “Win-Win” Options vs. Trade-offs

To identify sustainable energy options, policy-makers need to consider the economic, social and environmental aspects of sustainable development. Options that lead to improvements in all three indices are referred to as “win-win” options. Once “win-win” options are realised, policymakers are able to make tradeoffs among other available options.

Incorporating environmental and social externalities into energy decision-making is particularly important, where concerns (like pollution from nuclear or fossil-fuelled plants, and inundation at hydro plants) have hampered project implementation. Environmental and social concerns need to be addressed early—at the sectoral and regional planning stages, rather than at the final stage of project SDA. Unfortunately, when dealing with energy sector issues at this aggregate planning level, the application of many project-level valuation techniques becomes extremely difficult. First, the impacts are difficult to value (e.g., health effects of pollutants from coal-fired generating stations, biodiversity loss from large scale hydro storage, and impacts of greenhouse gas emissions). Doubts raised about the valuation techniques themselves, divert attention away from critical policy trade-offs. Second, many techniques appropriate at the micro-level, are less effective at the sector level. Thus, contingent valuation is more valid where respondents can be asked specific questions about local impacts of a project to which they can relate, and difficult to apply at the sector level where one deals with large numbers of technology, site and mitigation options.

In countries where inappropriate policies have encouraged wasteful and unproductive uses of some forms of energy, 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 and social protection (reduced energy related environmental and social costs). However, it may not be possible to satisfy all the above goals simultaneously. For example, in some developing countries where existing levels of per capita income and energy consumption are very low, affordable energy might have a high priority, to meet basic energy needs.

The economic efficiency criterion which maximises the value of net output from all scarce resources in the economy (including energy) is usually applied through traditional cost-benefit analysis (CBA), which also subsumes purely energy-oriented objectives such as energy efficiency and conservation. Furthermore, costs arising from energy-related adverse environmental impacts may be included in the energy economics analytical framework by monetarily valuing such impacts, to determine how much other benefits society should be willing to forego, in order to avoid environmental damage. When valuation is not possible, methods like multicriteria analysis (MCA) could be used to supplement CBA.

Energy use and production may be improved in several ways to make them more sustainable. First, energy efficiency may be increased by supply and demand side improvements. Second, environmentally and socially more benign technologies can be introduced, including fuel switching and renewable energy sources. Finally, price, institutional and regulatory reforms could contribute to SED.

2.3. SED Options Matrix and Renewable Energy Costs and Benefits

Table 1 shows typical impacts of selected energy options on the three elements of sustainable development (+ is beneficial and – is harmful). While, efficient supply side options (e.g., 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 decreased energy supply, the social impacts are unclear. 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 help reduce air pollutants such as CO₂ 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 power generating costs, renewables may be more expensive than fossil fuels, especially if environmental and social externality costs are ignored.

Table 1

Selected Sustainable Energy Development (SED) Options Matrix I

Option	Impact		
	Economic	Environmental	Social
Supply Efficiency	+	+	
End Use Efficiency	+	+	+
Advance Technologies	–	+	+
Renewables	–	+	+
Pricing Policy	+	+	+/-
Privatisation/ Decentralisation	+	+/-	+/-

Broader social, environmental and economic benefits and costs associated more specifically with renewable energy options are summarised in Table 2.

3. APPLYING THE SED FRAMEWORK

In this section, practical case studies are presented which illustrate the application of the ideas presented earlier. While many sophisticated energy and electricity models exist for planning and policy analysis, we focus below on simpler SED examples linked to sustainability and renewable energy.

3.1. Global Scale: Carbon Mitigation, Energy Efficiency and Sustainable Development Paths

The energy-related problem involving greenhouse gas mitigation provides an interesting example of how such an integrative framework could help incorporate climate change policies within a national sustainable development strategy. The total GHG emissions rate (G) may be decomposed as follows:

$$G = [Q/P] \times [Y/Q] \times [G/Y] \times P;$$

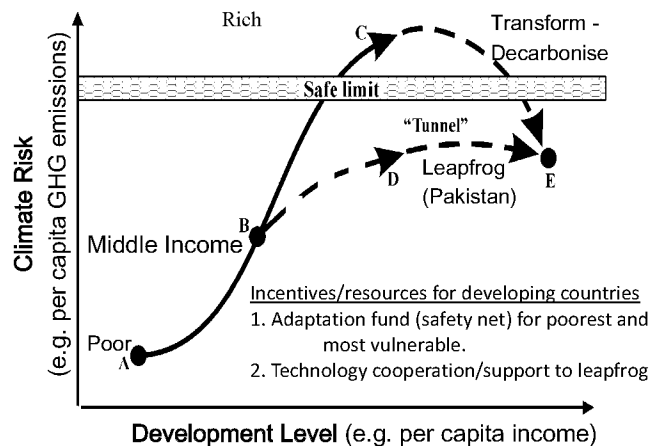
where $[Q/P]$ is quality of life (Q) per capita; $[Y/Q]$ is material consumption (Y) required per unit of quality of life; $[G/Y]$ represents GHG emissions (G) per unit of consumption; and P is population.

A high quality of life is consistent with low total GHG emissions, provided that each of the three terms on the right hand side could be minimised. Reducing $[Y/Q]$ implies ‘social decoupling’ (or ‘dematerialisation’) whereby satisfaction becomes less dependent on material consumption—through changes in tastes, behaviour and social values. Similarly $[G/Y]$ may be reduced by ‘technological decoupling’ (or ‘decarbonisation’) that reduces the intensity of GHG emissions in consumption and production. Finally, population growth could be reduced, especially where emissions per capita are already high.

Focusing on the decarbonisation term $[G/Y]$, Figure 7 illustrates the different challenges facing developed and developing countries [Munasinghe (2011)]. On this stylised curve of environmental risk against a country’s level of development, poor nations are at point A (low GHG emissions and low GNP per capita), rich nations are at point C (high GHG emissions and high GNP per capita), and intermediate countries are at point B.

The sustainable development path to be followed by any country depends on its position along this curve. Industrial countries (already exceeding safe limits) should mitigate and follow the future growth path CE, by restructuring their consumption and production patterns to delink carbon emissions and economic growth, thereby making their development path more sustainable. Middle income countries could adopt innovative policies to “tunnel” through (along BDE—below the safe limit), by learning from past experiences of the industrialised world. Poorer developing countries should be encouraged (with technical and financial assistance) to increase their consumption and production more sustainably by following a growth path that is less carbon-intensive. Finally, the poorest countries and poorest groups must be provided an adaptation safety net, to reduce vulnerability to climate change impacts.

Fig. 7. Balancing the Development Path and Climate Risk



Clearly, the same generic arguments may be applied to all forms of natural resource use, to ensure that the basic consumption needs of the poor are met while limiting excessive consumption of the rich within the bounds of planetary sustainability.

3.2. National/Sectoral Scale: Energy Sector Planning in Sri Lanka

The incorporation of environmental and social externalities into decision-making is particularly important in the electric power sector. A Sri Lanka study [Munasinghe (2010)], demonstrates how externalities could be incorporated into power system planning in a systematic manner. Sri Lanka presently depends largely on hydro power for electricity generation, but over the next decade the main choices seem to be large coal- or oil-fired stations, or hydro plants whose economic returns and environmental impacts are increasingly unfavourable. In addition, a wide range of other options (such as wind power, increasing use of demand side management, and system efficiency improvements), complicates decision-making—even in the absence of the environmental concerns.

The methodology involves the following steps: (a) definition of generation options and their analysis using sophisticated least-cost system planning models; (b) selection and definition of attributes that reflect planning objectives; (c) explicit economic valuation of those impacts for which valuation techniques can be applied with confidence—the resultant values are then added to the system costs which is the main economic attribute; (d) quantification of those attributes for which explicit economic valuation is inappropriate, but for which suitable quantitative impact scales can be defined; (e) translation of attribute value levels into value functions (known as “scaling”); (f) display of trade-offs to facilitate decision making; and (g) definition of options for further study, which also involves discarding eliminating inferior options.

Main Results

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

A limited number of criteria or attributes should be selected with care, to reflect issues of national as well as local project level significance. CO₂ emissions were used as proxy for the potential impact on global warming. Health impacts were measured through population-weighted increments in both fine particulates and NO_x. To capture the potential bio-diversity impacts, a probabilistic index was derived. Employment creation was used as an illustrative social impact.

Figure 8(a) illustrates a typical trade-off curve for biodiversity. The “best” solutions lie closest to the origin. The trade-off curve is defined by the set of “non-inferior” solutions (or superior options) that are best in terms of both objectives. For example, on this curve, the option defined as “no hydro” is better than the option “wind”, in terms of both economic cost and biodiversity loss.

options, especially fluorescent lighting; (ii) whether the present transmission and distribution loss reduction target of 12 percent ought to be further reduced; (iii) possibilities of pressurised fluidised bed combustion (PFBC) technology for coal power; (iv) replacement of some coal-fired power plants (on the South coast) by diesel units; and (v) cooling system options for coal plants.

3.3. Local-project Scale: Multicriteria Analysis (MCA) of Renewable Energy Projects

Well accepted environmental and social assessment procedures at the project/local level may be readily adapted to assess environmental and social effects of micro-level activities. When monetary valuation of environmental and social effects is not feasible, MCA may be used. Here, we summarise how multi-criteria analysis (MCA) may be used to compare hydroelectric power schemes [Munasinghe (2011)]. The three main sustainable development issues considered comprise the economic costs of power generation, ecological costs of biodiversity loss, and social costs of resettlement.

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

Environmental, Social and Economic Indicators

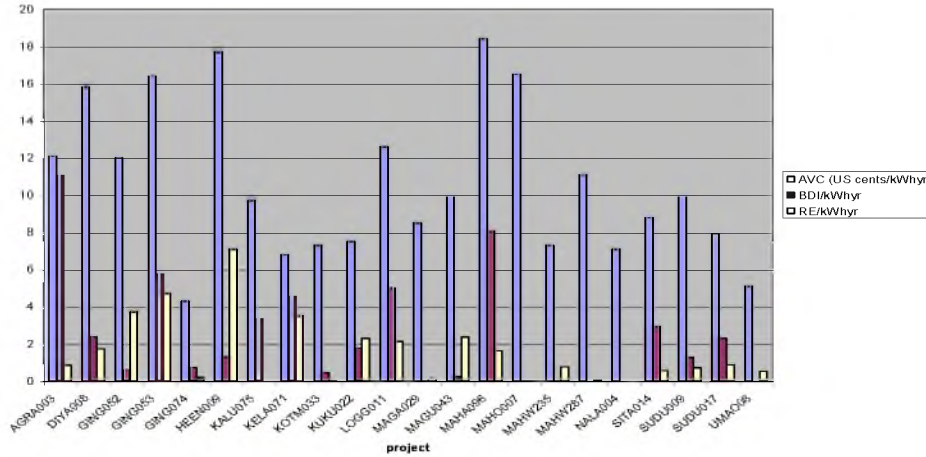
Sri Lanka has many varieties of endemic or endangered fauna and flora. Often, large hydro projects destroy wildlife at dam sites and in downstream areas. Hence, a biodiversity loss index was estimated for each hydroelectric site as the main ecological indicator (see previous case study). Although dam sites are usually in less densely populated rural areas, resettlement is still a serious problem. In general, people are relocated from the wet to the dry zone where the same level of agricultural productivity cannot be maintained, due to limited water and poor soil quality. Living standards often become worse and several problems (like malnutrition) could occur. Moreover, other social issues might arise, such as erosion of community cohesion and psychological distress due to changed living conditions. Hence, minimising the number of people resettled due to dam construction is an important social objective.

The project costs are available for each site, from which the critical economic indicator—average cost per kWh per year—may be estimated. The annual energy generation potential at various sites ranges from about 11 to 210 KWh (Figure 8). All three variables (biodiversity index, number of people resettled, and generation costs), are calculated per kWh of electrical energy generated at each site. This scaling removes the influence of project size and makes them more comparable.

Figure 10 provides a more comprehensive three-dimensional analysis of sustainable development indicators for these hydropower sites, where the respective axes represent economic, ecological, and social objectives. The closer to the origin any given coordinate point is plotted, the better is the corresponding project in terms of achieving these three

objectives. This type of analysis gives policy-makers some idea about which project is more favourable from a sustainable energy development perspective.

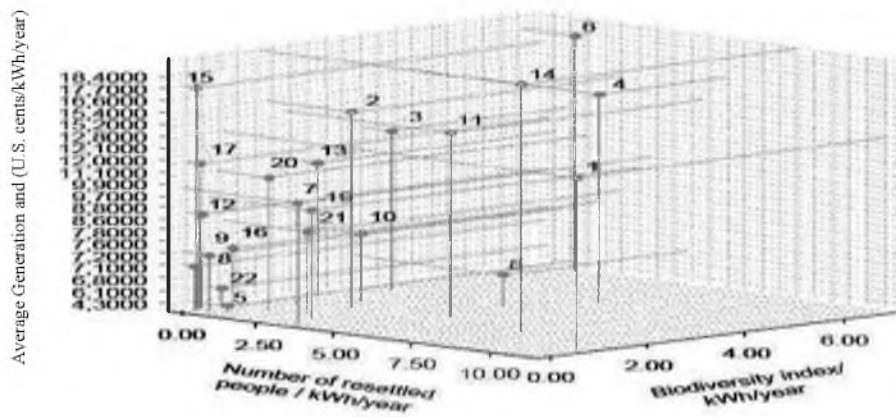
Fig.9. Average Generation Costs (AVC), Biodiversity Index (BDI), and Number of Resettled People (RE) by Hydroelectric Project.



Note: All indices are per kWh per year. Numbers of people resettled and biodiversity index are scaled by the multipliers 10^{-5} and 10^{-9} respectively, for convenience. Values across top of the graph indicate annual energy generation in gigawatt hours (GWh).

Suppose we arbitrarily give all three objectives an equal weight. Then, each project may be ranked according to its absolute distance from the origin. For example, rank 1 is given to the one closest to the origin, rank 2 is the second closest, etc. (Figure 10). On this overall basis, from a sustainable energy development perspective, the most favourable project GING074 (project 5) is closest to the origin, whereas the least favourable one MAHA096 (project 14) is the furthest.

Fig. 10. Three Dimensional MCA of Sustainable Development Indicators for Hydropower Options.



Source: Munasinghe (2011).

Conclusions

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

The MCA approach used here could be improved. First, for simplicity each major objective is represented by only one variable. There may be additional key variables which could describe other important sustainable development impacts. Further analysis that includes other attributes might provide new insights. Second, the study could be extended to include other renewable sources of energy. Finally, more sophisticated 3D-graphic techniques may yield better and clearer representations.

4. CONCLUSIONS AND KEY POLICY IMPLICATIONS FOR PAKISTAN

The SED-INEP approach based on sustainomics leads to several generic conclusions.

- (1) Integrated solutions are the most effective where energy policies are incorporated within the sustainable development strategy, using the SED-INEP framework.
- (2) Transformation of energy systems is an urgent task because the issues are complex and serious, while changes take time to become effective. Applying the MDMS principle is important since we know enough already about technologies, policies and methods to take immediate steps to solve the problems.
- (3) Energy options that have an important role, include energy efficiency (which yields quick returns), demand management, renewable energy and advanced technologies.
- (4) Renewable energy is becoming less costly and more widely available, with increasing economies of scale. More rapid diffusion is possible with investment incentives and portfolio standards, better integration within conventional energy systems (e.g., feed in tariffs to power grids), including externality costs within fossil fuel prices, and improved R&D through training and tax credits, etc.
- (5) SDA analysis will identify win-win energy solutions that simultaneously meet economic, social and environmental criteria, while facilitating trade-off decisions where different criteria might conflict.
- (6) The full mix of policy options need to be applied, including sustainable energy pricing and economic incentives, regulation, advertising, etc. to encourage more sustainable consumption and production, especially with respect to energy use. In the long run changing social values will be critical.

- (7) Energy poverty can be reduced sharply, by supplying basic energy needs of all human beings, and focusing on improved cooking stoves, cleaner fuels for homes, and greater access to electricity.

SED Options for Pakistan

The SED-INEP framework helps to identify broad issues and strategic options to support Pakistan's sustainable development efforts. As shown below, energy sector issues are complex and the structural changes required to address them calls for far-sighted leadership, guided by sustainability principles.

Pakistan's present (2012) total installed generation capacity is about 19.6 GW (hydro, fossil, independent power producers or IPPs, and nuclear sources). The existing capacity of thermal power generation in Pakistan stands at 12.6 GW, which is almost two-third (65 percent) of the country's total generation capacity. Hydro energy is the second largest source of electricity and accounts for 33 percent of total power generation. The national electricity demand is projected to increase to around 40,000MW by 2020 [WAPDA (2013)]. There is need for a high and sustained growth in energy supply and infrastructure capacity of 7-8 percent per annum to support economic growth in the country.

The strategic shift away from fossil fuels must be encouraged. Demand for energy in Pakistan has grown almost six-fold from 1980 to date and is expected to double again by 2015. The high dependence on hydrocarbons as the primary energy source needs to be reduced, to make energy development more sustainable.

From the perspective of *Environmental Sustainability*, SED analysis indicates that increasing hydro generation capacity would be a clean, and low cost method of meeting rising demand. However, the water storage capacity is decreasing rapidly due to sedimentation of existing reservoirs, caused by unsustainable environmental practices upstream. There is an urgent need to commence construction of large storage reservoirs to hold the water flowing in the only river that runs through Pakistan (Indus), while strengthening environmental and social safeguards. Better water storage will not only help with power generation but also help provide irrigation and potable water, promote fisheries and sustain communities. Pakistan has a potential for producing over 50 GW of electricity, if hydro power resources are used effectively.

Economic Unsustainability arises from costly electricity shortages and system losses. With the increase of population, urbanisation and industries, the demand-supply gap is large. Electricity shortfalls reached a peak of 8,500 megawatts (MW) in June 2012 or more than 40 percent of national demand. Load-shedding of up to 12-16 hours a day across the country has led to economic costs as high as 4 percent of GDP. Reasons for poor supply include inefficient energy utilisation, indiscriminate use of subsidies, lack of public awareness, ineffective or unenforced legislation, poor governance, under-developed infrastructure and theft, etc. The existing energy infrastructure needs to be urgently upgraded, transmission and distribution networks made more efficient, and the capacity of major water reservoirs restored.

An important manifestation of *Social Unsustainability* is the high incidence of energy poverty in Pakistan. Although overall energy demand continues to rise, per capita energy use remains one of the lowest in the world, especially among the poor. There are several reasons.

First, the energy sector is inefficient, and it is estimated that almost 20 percent of Pakistan's overall energy consumption could be saved by 2015. Such energy conservation will be more cost effective than building new generation capacity. Second, power generation from expensive thermal sources makes electricity less affordable to the poor. Third, the poor are still highly dependent on biomass and traditional fuels, which are inconvenient. Continued dependence on bio mass and petroleum products could worsen poverty issues.

In terms of indigenous energy resources; Pakistan is rich in natural gas, hydroelectricity, and coal. However, due to the high consumption of oil and gas, experts predict that indigenous oil reserves will be exhausted by 2025, and natural gas by 2030. Meanwhile, hydroelectricity supply is imperilled by climate change, with less rainfall reducing river flows. This trend is exacerbated by wasteful water consumption. For example, decades of water-intensive agriculture practices like subsidised flood irrigation—have helped deplete surface water tables and prompted farmers to make excessive use of electric tube wells to extract groundwater.

Alternative energy is being used only at a miniscule scale in the current energy mix but by 2030, the government plans to have a minimum of 5.0 percent of total commercial energy supply provided by wind, solar, and bio-waste (i.e., 2.5 percent of Pakistan's overall energy generation will come from new renewable sources). In addition, the government plans to invest in the country's vast coalfields (in Thar) where 200 billion tons of reserves have lain dormant since their discovery more than twenty years ago. Clean coal technology has more potential to address Pakistan's current energy supply crisis and to potentially reduce dependency on expensive imported oil and gas.

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