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Towards Sustainable Energy Development : assessing the economic, social and environmental implications of hydropower projects in Sri Lanka

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ABSTRACT

The concept of sustainable development has evolved to encompass three major points of view: economic, social and environmental. Meanwhile, energy has emerged as one of the key resources whose use affects the economic, social and environmental dimensions of sustainable development. In recent times, growing energy demand has also become associated with global climate change, which poses an unprecedented challenge to humanity. Given the wide-ranging potential impacts of energy production and consumption on sustainable development, this paper reviews the linkages between these two topics. A case study is presented based on the application of sustainomics principles, including multi-criteria analysis, to assess the sustainable development implications of hydroelectric power generation in Sri Lanka. Three key variables, (electricity supply costs, numbers of people resettled, and biodiversity loss) are selected, to represent the economic, social and environmental dimensions. This type of analysis helps policy-makers to compare project alternatives more easily and effectively. The simple graphical presentations are more readily comprehensible, and identify the sustainable development characteristics of each scheme quite clearly. The multi-dimensional analysis supplements the more conventional cost benefit analysis based on economic analysis alone.

Towards Sustainable Energy Development : assessing the economic, social and environmental implications of hydropower projects in Sri Lanka

Risa Morimoto, Mohan Munasinghe and Peter Meier[1]

1. Background

The world is currently exploring the concept of sustainable development or 'development which lasts'. Originally popularized through the work of the World Commission on Environment and Development, sustainable development has become widely accepted by decision makers worldwide, following the post-Rio consensus on the United Nations' Agenda 21 [*WCED 1987, UN 1993*]. The goal is an approach that will (*inter alia*) permit continuing improvements in the present quality of life at a lower intensity of resource use, thereby leaving behind for future generations an undiminished stock of productive assets (i.e., manufactured, natural and social capital) that will enhance opportunities for improving their quality of life.

As yet, there is no universally acceptable practical definition of sustainable development. However, the concept has evolved to encompass three major points of view: economic, social and environmental, as shown in Figure 1 [*Munasinghe 1993*]. Each viewpoint corresponds to a domain or system that has its own distinct driving forces and objectives. The economy is geared mainly towards improving human welfare, primarily through increases in the consumption of goods and services. The environmental domain focuses on protecting the integrity and resilience of ecological systems and subsystems. The social domain emphasizes the enrichment of human relationships and achievement individual and group aspirations.

Although no specific approach or framework exists, that attempts to define, analyse, and implement sustainable development, Munasinghe [*1993*] proposed the term sustainomics to describe "a transdisciplinary, integrative, comprehensive, balanced, heuristic and practical meta-framework for making development more sustainable." Sustainomics seeks to weave the knowledge from existing disciplines into new concepts and methods that could address the many facets of sustainable development – from concept to actual practice [*Munasinghe 2000*]. Thus, this framework would provide a comprehensive and eclectic knowledge base to support sustainable development efforts -- see Figure 1(b).

Meanwhile, energy has emerged as one of the key resources whose use affects the economic, social and environmental dimensions of sustainable development. First, it has long been perceived as a major driving force underlying economic progress. Second, energy production and use are strongly interlinked with the environment. Third, energy is a basic human need, which significantly affects social well-being. In recent times, growing energy demand has also become associated with global climate change, which poses an unprecedented challenge to humanity. The wide-ranging potential impacts of energy production and consumption on sustainable development suggest that the linkages between these two topics need to be critically analysed. Accordingly, this paper presents a case study based on the application of sustainomics principles (i.e., using multi-criteria analysis) to assess the economic, social and environmental implications of hydroelectric power development in Sri Lanka.

[1] Cambridge University, Cambridge, UK; Munasinghe Institute for Development (MIND), Colombo, Sri Lanka; and IDEA Inc, London, UK; respectively.

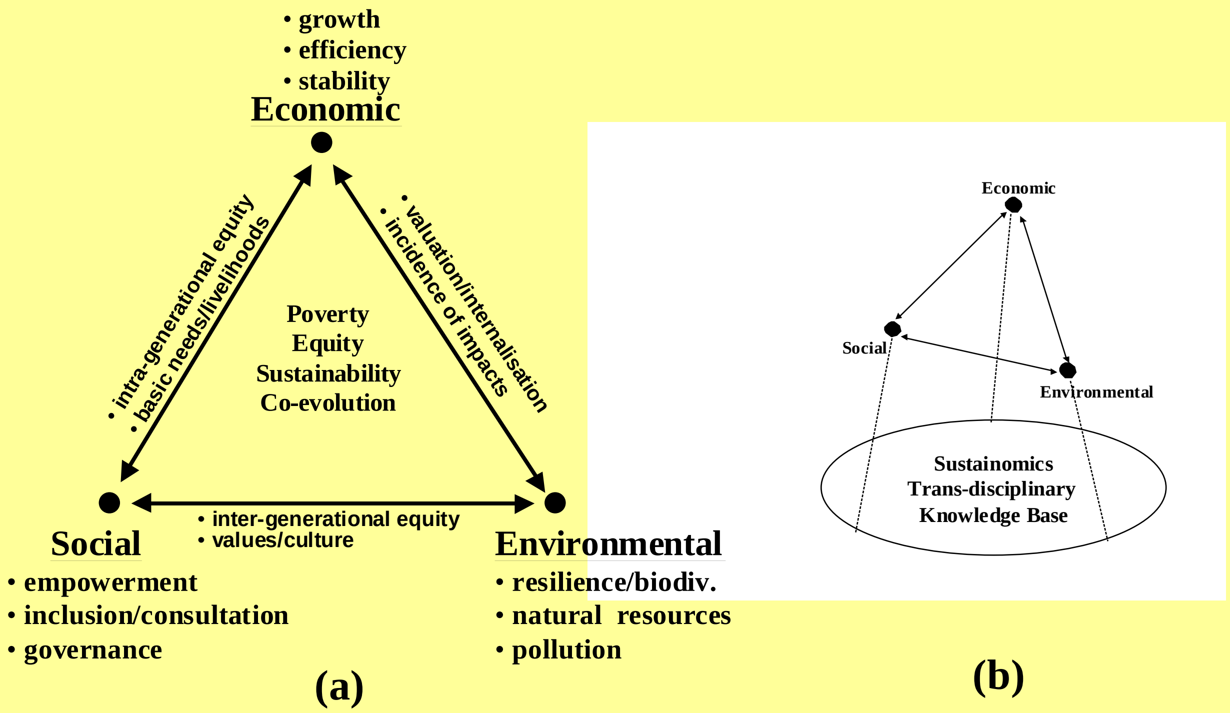


Figure 1 (a). Elements of sustainable development
1 (b). Sustainable development triangle supported by the sustainomics framework.
Source: adapted from Munasinghe [3,4]

The paper comprises five parts. The second section following this introduction, contains a brief introduction to the power sector in Sri Lanka, i.e., a review of the past history and illustration of the transition from a predominately hydro to a mixed hydro-thermal power system. The third section explains the theory and the methodology used in the study. The results are analysed in section four. Finally, section five sets out some key conclusions.

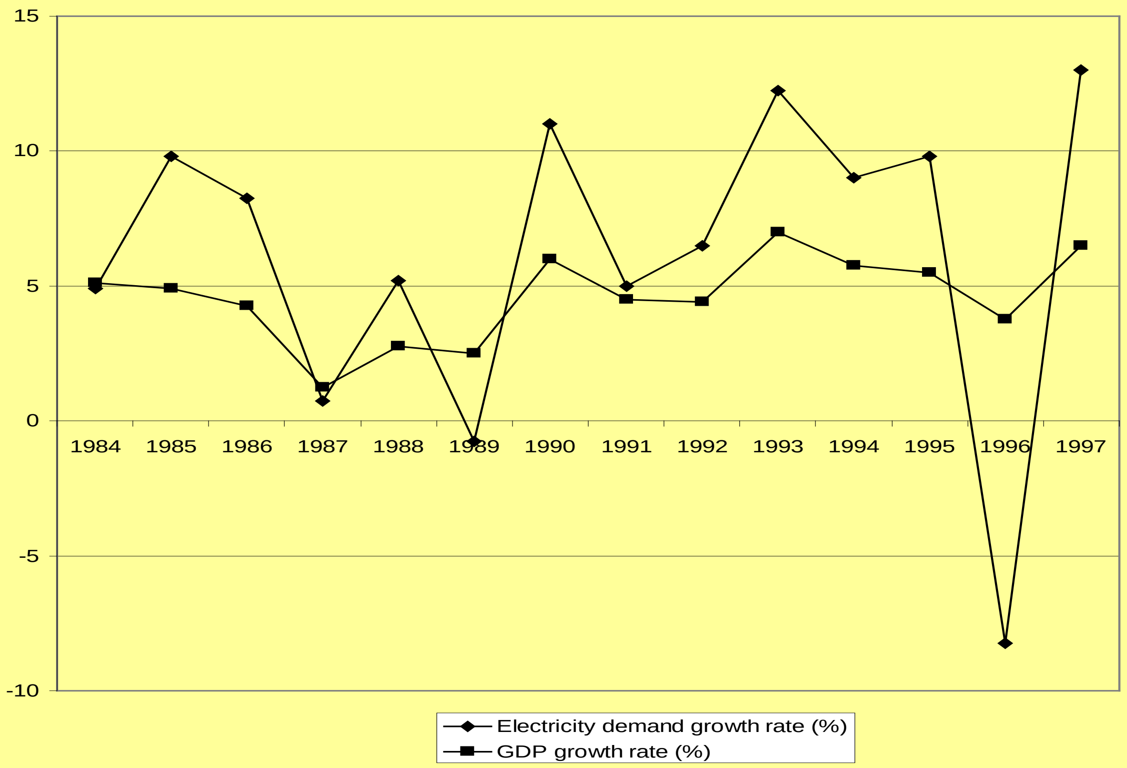
2. Brief Review of the Sri Lanka Power Sector

There is a strong correlation between growth rates of Gross Domestic Product (GDP) and electricity demand in Sri Lanka as shown in Figure 2(a) (CEB 1999). The value of the Pearson correlation is 72%[2]. Serious droughts in 1996 meant that Sri Lanka experienced a severe power crisis and adversely affected economy. The growth rate of GDP in 1995 was 5.45%, which decreased to 3.76% in 1996. Then, it shows a recovery to 6.45% in 1997. The electricity demand growth rate follows a similar pattern, i.e., it was 9.82% in 1995, which declined to –8.35% in 1996 and then increased to 12.57% in 1997.

The demand for electricity in Sri Lanka is increasing very rapidly. In 1998, the total electricity demand was 5689 GWh and energy demand is doubling every 10 years (CEB 1999). Currently, Sri Lanka depends largely on hydropower for power generation (see Figure 2(b)). Over 60% of energy demand (3351 GWh) was met by hydropower in 1998, about 30% (1599 GWh) by thermal power, and less than 5% (159 GWh) through self-generation (CEB 1999). In Sri Lanka, approximately 1115MW of major hydro capacity, capable of providing (on average) 3858 GWh of energy annually, have been developed (CEB 1999). Table 1 shows existing, committed and candidate power stations in Sri Lanka.

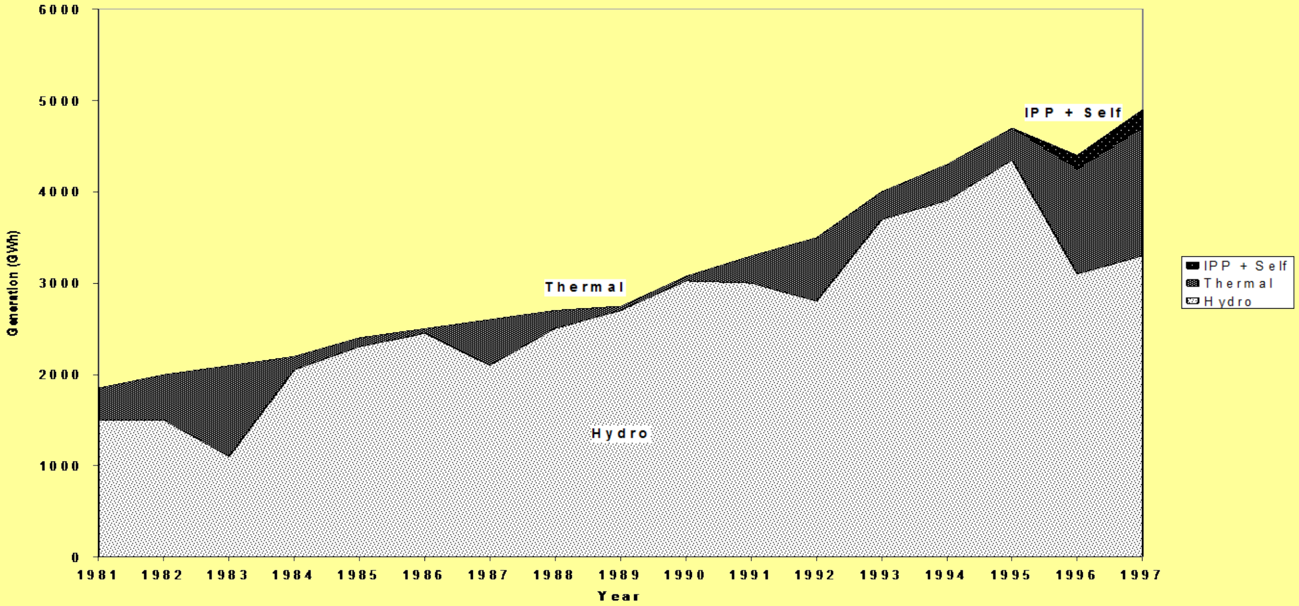
[2] Correlation is significant at the 1% level.

Figure 2(a)   GDP and Electricity demand growth rates in Sri Lanka



Source: CBSA (1998), statistical digests of relevant years (Information Management Branch (CEB)

Figure 2(b)   Hydro-thermal energy share in Sri Lanka



Source: CEB (1999)

Table 1 *Existing, committed and proposed power stations in Sri Lanka*

Hydro power plant	Capacity (MW)
Victoria	210
Kotmale	201
Upper Kotmale*	150
Uma Oya*	150
Randenigala	122
Samanalawewa	120
New Laxapana	100
Polpitiya	75
Kukule	70
Canyon	60
Wimalasurenora	50
Old Laxapana	50
Rantambe	49
Gin (Ganga)*	49
Bowatenna	40
Broadlands*	40
Ukuwela	38
Molagolla*	27
Inginiyagala	11
Udawalawewa	6
Nilambe	3

Source: Munasinghe (1994a); CEB (1999) (*: proposed)

The current electrification rate in Sri Lanka is about 47%, and the majority of the rural population does not yet have access to electricity (CEB 1999). The current target electrification rate of CEB (Ceylon Electricity Board) for 2005 is 85%, although a more realistic figure may be around 75%. About 400,000 households without access to electricity use automobile batteries to power lamps, radios and TVs. The remainder use kerosene for lighting and firewood for cooking.

The development of hydropower in Sri Lanka started to draw attention in 1918. However, hydropower is not always a reliable source of energy. Historically, Sri Lanka has faced droughts approximately every 4 years. For example, in 1992, a severe drought dried up major reservoirs so that the power supply had to be rationed to users for four months. Thus, the CEB plans to install a 400MW-coal plant to supplement the hydropower system, although environmental groups are opposing this plan. Moreover, Sri Lanka lacks indigenous fossil fuels. Therefore, they must be import oil and coal from foreign countries, which reduces the country's exchange reserves. Power sector management in Sri Lanka is now in a transitional period, moving from a predominately hydropower system to a mixed hydro-thermal power system (e.g., coal and oil). Table 2 shows committed power plant additions.

Renewable energy sources are expected to provide only a fraction of Sri Lanka's power needs in the coming years. However, since they could play a key role in sustainable energy development, we briefly review the current status. Renewable sources of energy such as mini-hydro, solar, and wind have started to draw much attention recently. In the 1980s, the government embarked on the promotion of solar photovoltaics (PV) for rural domestic use. Although solar PV is accepted as clean and the most suitable form of renewable, decentralized electricity by policy makers, they are yet to be fully realized in Sri Lanka due to its high costs (Gunaratne 1994). Solar home systems have been commercialized, especially by villagers in rural area. There are pilot projects of wind power systems (total capacity of 3MW) in southern region. Mini-hydro schemes (i.e., projects less than 5 MW) are also considered as an important alternative to large dams. Development of mini-hydro dates back to early 20th century, especially in tea plantation industries. The transition from mini-hydro to grid electricity supply started in the 1960s. However, mini-hydro power regained its popularity during the early 1980s due to an increase in the costs of grid supplied power. Currently, mini-hydro supplies about 200kW of electricity (CEB 1999). The number of identified mini-hydro sites is about 257 (NPL 1996, Fernando 1998). There are a number of proposals for Dendro-thermal power. Biomass, wave, and other renewable sources of energy are also under consideration. The current obstacle of expanding market for such renewable energy is largely its high capital costs. However, a rapid decrease in its costs will be expected as a result of advanced technology.

Table 2 Committed power plant additions

HYDRO PLANTS	Ins. Cap. (MW)	Annual Average Energy (GWh)
Kukule Power Plant (commissioning – 2003)	70	306
Upper Kotmale Power Plant (commissioning – 2006)	150	535
THERMAL PLANTS		Max Energy Capability (GWh)
Sapugaskanda Diesel Power Plant (commissioning – 2000)	40	273
Kelanitissa Combined Cycle Power Plant (commissioning – 2002)	150	1110
Kerawalapitiya Combined Cycle Power Plant (commissioning – 2003)	150	960
West Coast Coal Power Plant (commissioning – 2004)	300	1970
INDEPENDENT POWER PRODUCEDURES		Min. Guaranteed Energy (GWh)
Colombo Harbour Barge Mounted Power Plant (commissioning – mid 2000)	60	420
Kelanitissa Combined Cycle Power Plant (commissioning – 2001)	150	1209
Total Committed Capacity	1070	6803

Source: CEB (1999)

3. Methodology

Multi criteria analysis (MCA) is used in this study. MCA is designed to deal with multiple objectives and is a powerful tool to quantify and display the trade-offs that must be made between conflicting objectives which are difficult to compare directly. The three main sustainable development issues considered in this paper comprise the economic costs of power generation, ecological costs of biodiversity loss, and social costs of resettlement.

The principal objective is to generate additional kilowatt-hours (kWh) of electricity to meet the growing demand for power in Sri Lanka. In the analysis below, we assume that the benefits from each additional kWh are the same. We show that this assumption allows us to compare the sustainable development impacts of projects on the basis of the economic, social and environmental costs of generating one unit of electricity from different hydropower sites. Following the MCA approach, environmental and social impacts are measured in different (non-monetary) units, instead of attempting to economically value and incorporate them within the single-valued cost-benefit analysis framework

3.1 Economic indicator – power generation costs

The usual economic indicator in power project evaluation is the maximisation of net present value (NPV). However, in this study, minimising average generation costs per unit of generation will be used as the main economic comparator instead of NPV, based on the assumption that the total benefit per unit generated is the same for all projects under comparison.

Suppose we wish to rank two projects, according to the net benefit per unit of electricity generated. Then, project 1 will be better than project 2 if

$$(NB_1)/Q_1 = (B_1\text{-}C_1)/Q_1 \;>\; (NB_2)/Q_2 = (B_2\text{-}C_2)/Q_2 \qquad (1)$$

where NBi = net benefit for project i ; Qi = quantity of electricity generated from project i ; Bi= total benefit from project i ; and Ci = total economic cost of proect i.

Then, the following assumption may be made:

$$B_1/Q_1 = B_2/Q_2 \qquad (2)$$

This is a reasonable approximation, since one unit of electricity will produce the same total benefit within the electricity grid, irrespective of the source of generation (if transmission costs to connect generators to the grid, are comparable). Thus, the condition in Equation (1) can be expressed as:

$$(C_1/Q_1) > (C_2/Q_2) \qquad (3)$$

We may interpret Equation (3) to mean that the project with the lower cost per unit of electricity generated, is preferred. The costs Ci may be estimated as the present discoubted value of project costs, annuitised over the project lifetime, while Qi would be the average expected generation per year. Since this is an illustrative case study we have made an additional hidden asumption about equal plant factor, so that we may focus mainly on the energy generated and ignore capacity considerations (to first approximation).

3.2. Environmental indicator -- biodiversity index

Since biodiversity is a less familiar topic, we explain in some detail, the basis used to develop a preliminary biodiversity indicator to compare hydropower projects. In electric power plant evaluation, detailed site specific information at potential sites is unlikely to be available at the long-range system planning stage. Thus, the only quantification of biodiversity impacts that appears possible at this level of aggregation is a probabilistic estimate that gives the decision-maker advance information about the likelihood that a more detailed environmental impact assessment will reveal adverse effects on an endemic species, significant impacts on ecosystems of high biological diversity, or degradation of a habitat already in a marginal condition. It should be noted that endemicity and bio-diversity are not necessarily correlated, since an endemic species may be encountered in an area of low biodiversity, and areas of high biodiversity may contain no endemic species. However, endemic species in Sri Lanka are most likely to be encountered in areas of high biodiversity.

A biodiversity index must reflect several key characteristics. First is the nature of the impacted system itself. In Table 3, the main agro-ecological zones encountered in Sri Lanka are ranked and assigned a value (w_j) that captures the relative biodiversity value of different habitats. The scale is to be interpreted as a strict ratio scale (i.e. zero indicates zero amount of the characteristic involved, and a habitat value of 0.1 implies ten times the value of a habitat assigned the value of 0.01). The second element concerns the *relative* valuation, because the *value* of the area lost is a function of the proportion of the habitat that is lost. For example, the loss of the *last* hectare of an ecosystem would be unacceptable, and hence assigned a very large value (even if the habitat involved were of low biodiversity, such as a sand dune) whereas the loss of one hectare out of 10,000 ha would be much less valuable.

Table 3. Relative biodiversity values of agro-ecological zones in Sri Lanka

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

Source: adapted from Meier and Munasinghe [*1994*].

The total biodiversity index value associated with site i, is defined as:

$$E_i = \sum_j w_j . A_{ij} \qquad (4)$$

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

Since Ei would tend to be correlated with reservoir size (i.e., land area inundated and energy storage capacity), two further scaled indices may be defined as follows:

$$Fi = Ei / [\sum_j Aij] = Ei / [\text{Total land area affected at site i}] \qquad (5)$$

$$Gi = Ei / [\text{Hydroelectric energy generated per year at site i}]$$

Thus, Fi is the average biodiversity index value per hectare of affected land, and Gi is the average biodiversity index value per unit of energy produced per year. These formulae are applied to each hydro site under consideration, to determine their biodiversity index values.

3.3. Social indicator -- resettlement

Although dam sites are usually in less densely populated rural areas, resettlement is still a serious problem in most cases. In general, people are relocated from the wet to the dry zone where soils are less rich, and therefore the same level of agricultural productivity cannot be maintained.

In the wet zone, multiple crops including paddy, tobacco, coconuts, mangos, onions, and chilies can be grown. However, these crops cannot be cultivated as successfully in the dry zone, due to limited access to water and poor soil quality. Living standards often become worse and several problems (like malnutrition) could occur. Moreover, other social issues such as erosion of community cohesion and psychological distress due to change in the living environment, might arise. Hence, minimising the number of people resettled due to dam construction is one important social objective.

4. Results and Analysis

Table 4 presents a list of 22 hydro projects in Sri Lanka which are used in this study with the name of the associated river basin, and the quantity of electricity generated (for details see *CEB 1987, 1988*).

Table 4 Description of the projects

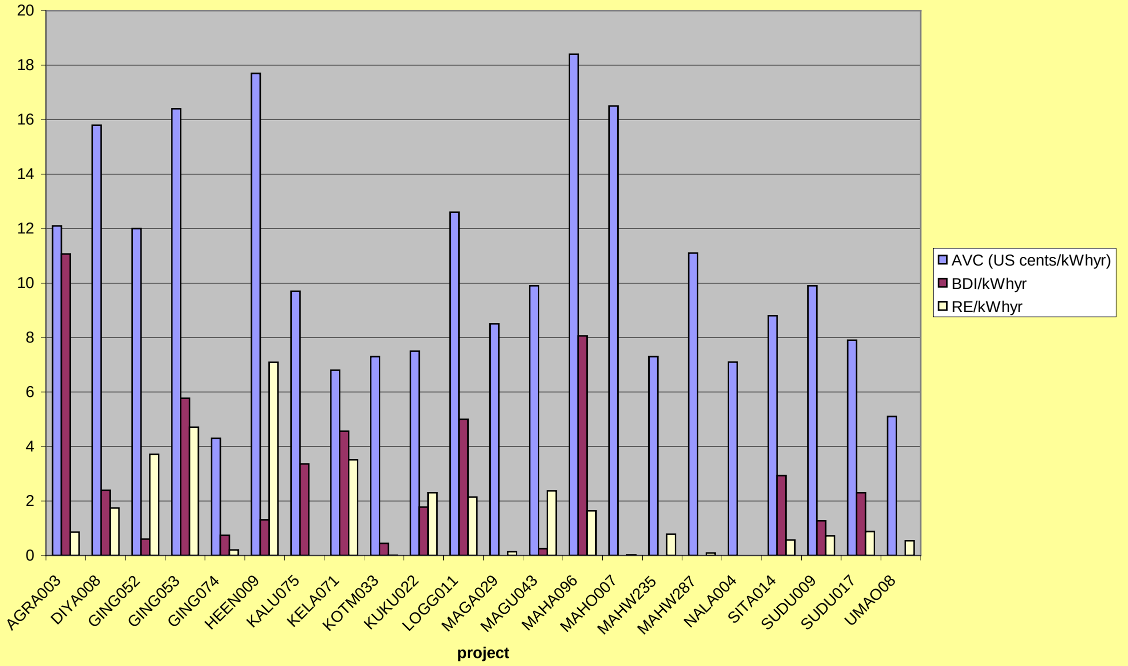
No	Projects	River basins	Quantity of electricity generated (GWhyr)
1	AGRA003	Agra Oya	28
2	DIYA008	Diyawini Oya	10.9
3	GING052	Ging Ganga	159
4	GING053	Ginag Ganga	210
5	GING074	Ging Ganga	209
6	HEEN009	Heen Ganga	19.9
7	KALU075	Kalu Ganga	149
8	KELA071	Kelani ganga	114
9	KOTM033	Kotmale Oya	390
10*	KUKU022	Kukule Ganga	512
11	LOGG011	Loggal Oya	22
12	MAGA029	Magal Oya	77.8
13	MAGU043	Maguru Oya	161
14	MAHA096	Maha Oya	33.5
15	MAHO007	Maha Oya	50
16	MAHW235	Mahaweli Ganga	83.4
17	MAHW287	Mahaweli Ganga	42.2
18	NALA004	Nalanda Reservoir	17.9
19	SITA014	Sitawaka Ganga	123
20	SUDU009	Sudu Ganga	79
21	SUDU017	Sudu Ganga	113
22	UMAO008	Uma Oya	143

* KUKU022 is a multi-purpose project so that there might be some non-power benefits which are not considered here.
Source: CEB (1987); CEB (1988)

All three variables used in the analysis (i.e., generation costs, biodiversity index, and number of resettled people) are weighted inversely by the amount of electricity generated. This scaling removes impacts of project size and makes them directly comparable.

From Figure 3, it is clear that on a per kWh per year basis, the project named AGRA003 has the highest biodiversity index, HEEN009 has the highest number of resettled people, and MAHA096 has the highest average generation cost. Some important comparisons may be made. For example, KALU075 is a relatively large project where the costs are low, whereas MAHA096 is a smaller scheme with much higher costs with respect to all three indices. Another simple observation is that a project like KELA071 fully dominates GING053, since the former is superior in terms of all three indicators. Similar comparisons may be made between other projects.

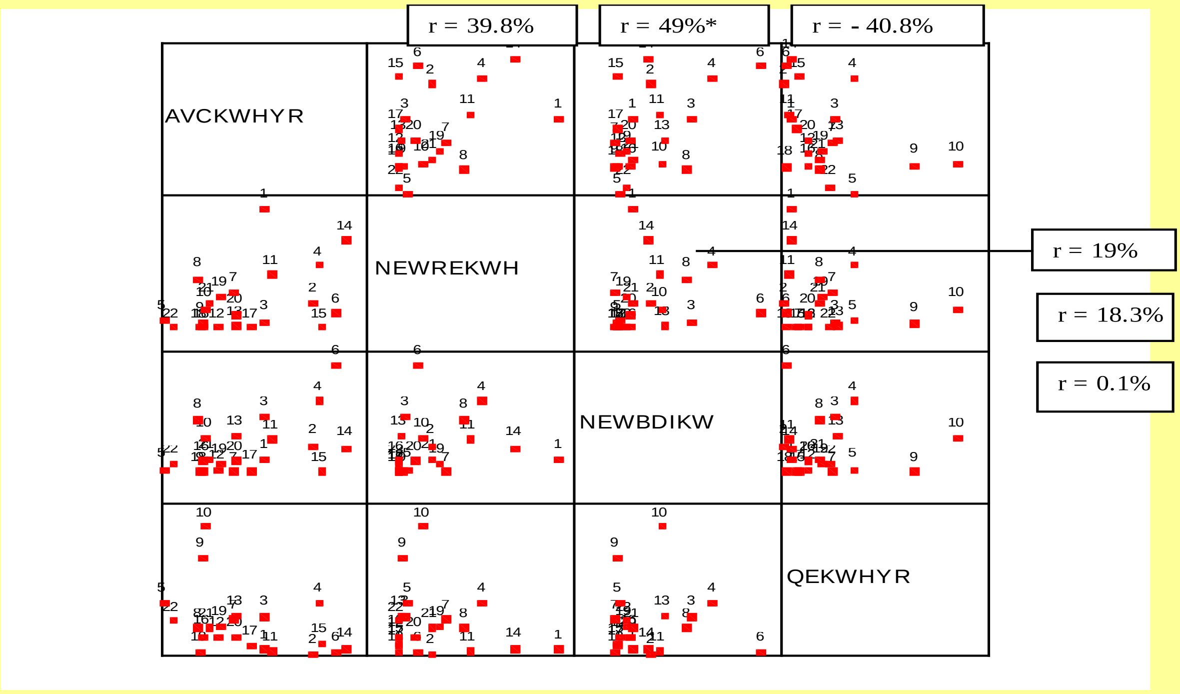
Figure 3 *Average generation costs (AVC), biodiversity index (BDI), and number of resettled people (RE) by hydroelectric project. All indices are per kWh per year. Generation costs are calculated using a 10% discount rate. Numbers of people resettled and the biodiversity index are scaled for convenience (by the multipliers 10^{-5} and 10^{-9} respectively).*



Source: CEB (1987); CEB (1988); Figures for biodiversity index (BDI) are obtained from Meier & Munasinghe (1994)

Figure 4 shows that there is a little correlation between quantity of electricity generated, average generation cost, number of resettled people, and biodiversity index.

Figure 4 *Correlation between the variables including quantity of electricity generated*[3]



r = Pearson correlation value; * = Significant at the 5% level

[3] AVCKWHYR=average generation cost (US cents/kWhyr), NEWREKWH=number of resettled people per kWhyr, NEWBDIKW=biodiversity index per kWhyr, and QEKWHYR=quantity of electricity generated (kWhyr).

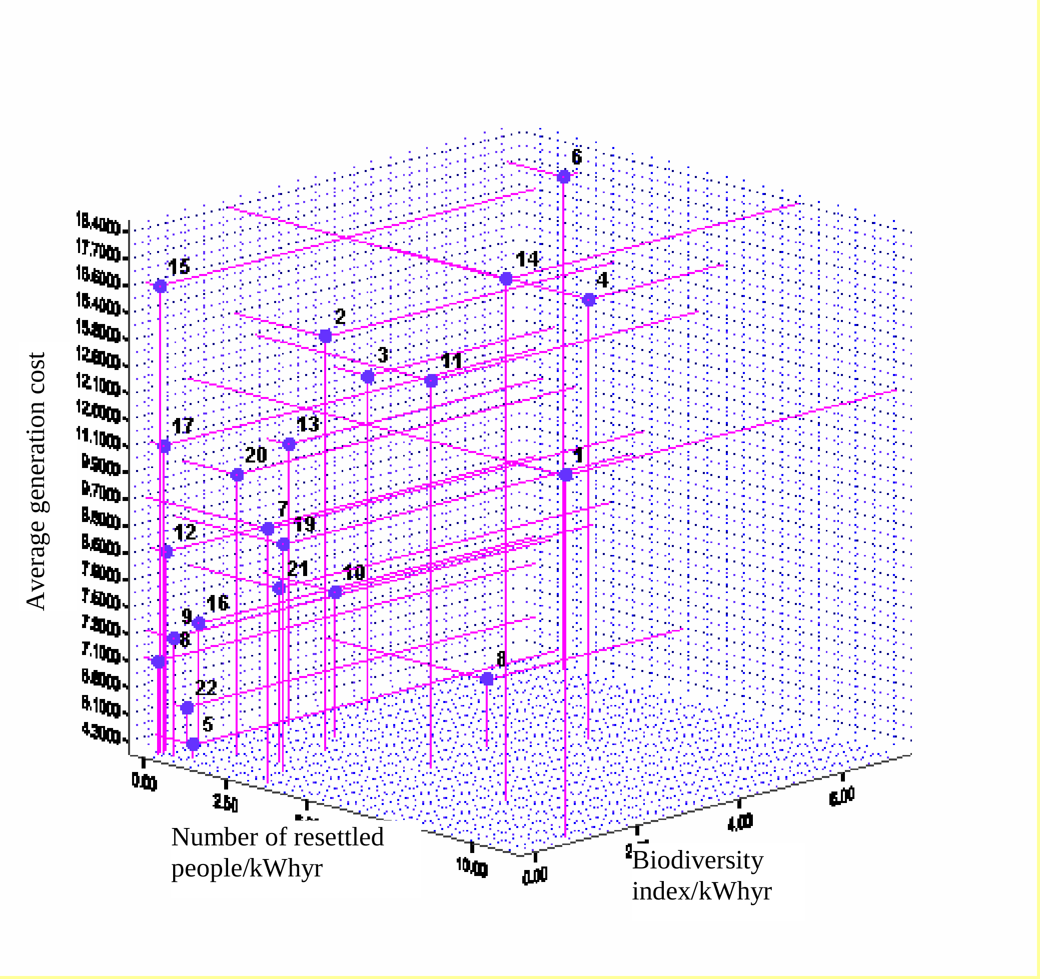
Suppose we arbitrarily give all the three objectives an equal weight. Then, each project may be ranked according to its absolute distance from the origin, given by the expression:

distance = [(x-coordinate)^2 + (y-coordinate)^2 + (z-coordinate)^2]$^{1/2}$

For example, rank 1 is given to the one closest to the origin, rank 2 is to the the second closest and so on.

Such a three-dimensional analysis of sustainable development indicators for these hydropower sites is provided in Figure 5. The axes represent economic, ecological, and social objectives, respectively. The distance from the origin to each coordinate point can be seen, and the closer to the origin, the better is the project in terms of achieving these three objectives. This type of analysis gives policymakers some idea abut which project is more favourable from a sustainable energy development perspective.

Figure 5 Three dimensional graphical analysis of impact on sustainable development

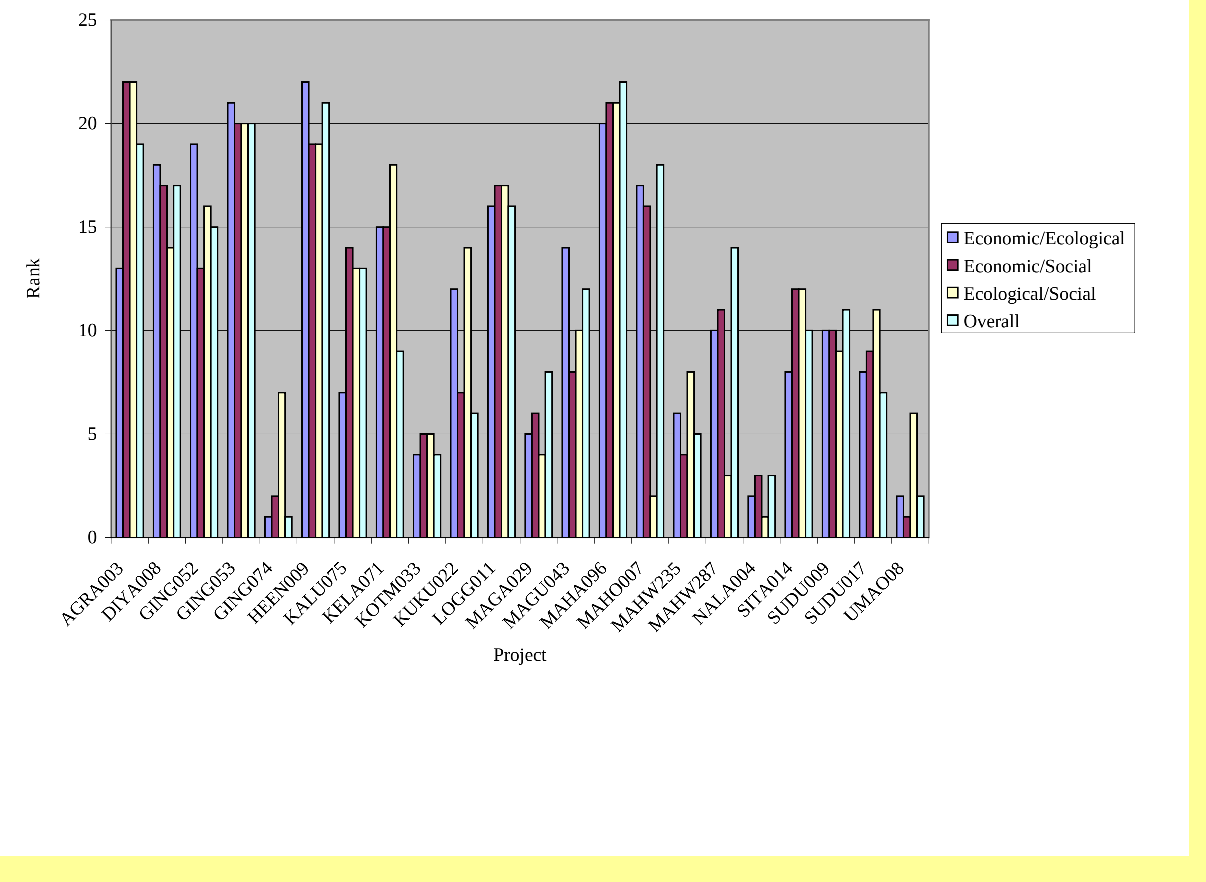


On this ad-hoc overall basis, from a sustainable energy development perspective, the most favorable project is GING074 (rank 1), whereas the least favorable one is MAHA096 (rank 22). A more complete set of rankings is provided in Table 5, where the three objectives are considered two at a time.

Table 5. Rankings of projects based on any two objectives

Project	Economic-Ecological	Economic-Social	Ecological-Social	Overall "3D MCA" (Fig 6)
1	13	22	22	19
2	18	17	14	17
3	19	13	16	15
4	21	20	20	20
5	1	2	7	1
6	22	19	19	21
7	7	14	13	13
8	15	15	18	9
9	4	5	5	4
10	12	7	14	6
11	16	17	17	16
12	5	6	4	8
13	4	8	10	12
14	20	21	21	22
15	17	16	2	18
16	6	4	8	5
17	10	11	3	14
18	2	3	1	3
19	8	12	12	10
20	10	10	9	11
21	8	9	11	7
22	2	1	6	2

Figure 6 Rank of each project



5. Conclusions

Sri Lanka has moved in recent decades from a predominantly hydroelectric system to a mixed hydro-thermal system. Renewable sources of energy are an important factor in successfully achieving the transition to sustainable energy development in Sri Lanka. MCA has been used in this paper, to assess the impact of hydropower projects on sustainable development.

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

There are several possible improvements that could be made in the MCA approach used here. First, for simplicity each major objective is represented by only one variable, assuming that all the other impacts are minor. In reality, there may be more than one variable which can describe the economic, social and environmental aspects of sustainable development. Further analysis that includes other variables may provide new insights. Second, a possible extension of this study is to include other renewable sources of energy in the analysis. Third, the choice of discount rates could affect the calculations and rankings relating to the economic variable. Fourth, exclusionary screening techniques (i.e., eliminating dominated projects like GING053 from the analysis, and focusing only on non-dominated ones) may provide a clearer picture. Finally, a more sophisticated 3D-graphic technique may yield a better and clearer representation [see *Tufte 1992*].

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