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AN EXTENDED CBA MODEL OF HYDRO PROJECTS IN SRI LANKA

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An extended CBA model of hydro projects in Sri Lanka

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Abstract.

This paper introduces an extended cost benefit analysis (CBA) model for the analysis of hydro projects, which includes social and environmental as well as economic aspects. A distinct feature of this CBA model is its treatment of uncertainty. The model treats uncertain inputs by specifying them as probability distributions. This feature is particularly necessary when trying to include social and environmental effects that are often less well known than engineering costs and economic benefits. A proposed hydro project in Sri Lanka is used as a case study. The impact of different discount rates on the project's value is also examined.

Key words: cost benefit analysis, dam, hydro power, Sri Lanka, sustainable development, uncertainty

1. Introduction

The three main aims of sustainable development are to improve economic, environmental and social conditions (Munasinghe 1993). However, traditional cost benefit analysis (CBA) often excludes or downplays environmental and social effects (Wang 1993). This paper introduces a CBA model that includes both environmental and social aspects for a proposed hydro project.

A distinct feature of this CBA model is its treatment of uncertainty. Computing an output value based on only one single value for uncertain inputs may not lead to a defensible result. Therefore, a range of possible outcomes (an approximate probabilistic distribution for each model output) is obtained by running the model repeatedly with random sampling of uncertain input values. This feature is particularly necessary when trying to include social and environmental effects that are often less well known than engineering costs and economic benefits.

This paper also looks at the importance of discount rates. According to economic growth theory, the discount rate is a function of economic and population growth rates, which are highly variable in the long term (Plambeck and Hope 1996). Since hydro projects have a long time horizon, a range of regional and time specific variable discount rates as well as the more usual fixed discount rates are used in this paper.

A proposed large hydro project, the Upper Kotmale Hydro Project (UKHP) in Sri Lanka is used as a case study. The Net Present Value (NPV) of the project is calculated under a range of assumptions. The main inputs which have significant impacts on the NPV are identified.

2. An extended CBA model

Large-scale dam construction involves numerous complex social, environmental and economic effects. However, most published case studies concentrate on only one or two major ones (Winpenny 1991). The poor social and environmental record of large dams has also been widely discussed for several decades (Thomas and Adams 1999; Farvan and Milton 1973; Ackerman et al. 1973; Goldsmith and Hildyard 1984). Traditional CBA does not usually include environmental and social effects, as they are difficult to measure and to value (Sullivan 1995). The lack of consideration of the environmental and social costs of large dams in economic terms implies that a good measure of the social profitability of projects remains elusive (WCD 2000).

A defensible CBA also has to deal with the uncertainties associated with a project. For example, technological problems which may occur in the future, possible environmental impacts, or delays in the construction period. Previous studies have often reached over-optimistic conclusions by failing to consider uncertainty (Winpenny 1991). The model introduced in this paper overcomes these problems by using probability distributions of all of important inputs to calculate a probability distribution of NPV. This method identifies which inputs have the greatest effect on the NPV of the project.

2.1. Case study: The Upper Kotmale Hydro Project in Sri Lanka

Hydropower plays an important role in many developing countries. Sri Lanka is highly dependent on hydropower, which provided more than 90% of the total electricity production over the period 1894-1993 (CEB 1994a). The total hydropower capacity and the average annual electricity generation are 1100 MW and 3800 GWh respectively in 1999 (CEB 1999). Historically, Sri Lanka is afflicted by severe droughts about every 4 years, which cause significant damage to its economy. Thus, thermal power plants comprising oil, steam, gas and diesel turbines were developed between 1962-1984 with a total installed capacity of 250 MW (CEB 1994a), which had risen to 460 MW by 1999 (CEB 1999). They operate mainly during the dry season as a supplementary source, since Sri Lanka has no resources of fossil fuels. Today, Sri Lanka, like many developing countries, is experiencing severe power shortage problems because of the high electricity demand caused by its rapid economic growth. The annual growth rate of electricity demand was about 12.6 %, and the annual national economic growth rate was about 6.5 % in 1997 (CEB 1999). The UKHP is proposed in order to lessen these serious power shortages. The UKHP is planned to be constructed over a 5-year period, beginning in 2001, and to have a capacity of 150 MW. The dam will be located upstream of the existing Kotmale reservoir.

The CBA model in this study includes the following major issues and excludes other minor ones in order to make the model simple and easy to understand. The main benefits of constructing the UKHP are as follows:

First, the utilization of indigenous and renewable energy sources such as hydropower is generally considered to be good for the environment. To replace the planned amount of annual power generation by the UKHP (532 GWh), coal power and gas turbines would have to generate approximately 520 GWh and 12 GWh of energy respectively (CEB 1994a). These alternative technologies are more likely to cause air pollution.

Second, the electricity supply from the project is expected to make a great contribution to the country's economic growth, since alternative sources of power generation may actually not be available.

There are also the following major costs associated with the project apart from the construction, maintenance and operation costs:

First is a large resettlement cost including compensation and development costs[1].

Second, an aesthetic loss due to reduction in water flow over the five major waterfalls, Devon, St Clair, Pundal Oya, Puna and Ramboda. This is likely to cause a loss in tourism revenue in the project area, as there is a significant dependence on the waterfalls for tourism.

Third, economic losses due to the inundation of land mainly used for tea production[2].

Fourth, possible accident costs since dam projects often involve several accidents during construction as well as during operation and maintenance, which may lead to deaths or injuries of workers.

Fifth, a sedimentation problem may arise, which would lower power generation as a result of the reduction in the effective storage ability of the dam.

Table I lists all the variables used in the extended CBA model to incorporate these costs and benefits, and their descriptions. The detailed equations for each variable will be found in Appendix A-I.

Table I. **Variables used in the extended CBA model.**

Variable	Description
PG (power generation)	The benefit of a supply of hydro electricity is calculated by multiplying the quantity of electricity generated by the price of electricity. A possible reduction in the value of electricity generated due to sedimentation, and changes in electricity prices, are also included in the equation[3].
CP (clean power)	The environmental benefit of avoiding damage from air pollution when generating an equivalent amount of power by the best alternative generation technology (a combination of coal power and gas turbines). This benefit will occur during the time when an alternative power generation technology is available.
EG (economic growth)	The benefit of economic growth facilitated by an assured power supply is expressed as avoided economic losses from power shortages. This benefit will occur during the time when an alternative power generation technology is not available.
CC (construction cost)	Construction costs of the power station and transmission facilities
OM (operation and maintenance cost)	O&M costs for running the hydropower station
RE (resettlement cost)	Compensation to individuals and for development such as new houses and infrastructure
IN (economic losses due to inundation of land)	Economic losses due to inundation is expressed by the financial value of lost land
LT (losses in tourism revenue)	Losses in tourism revenue as a result of reduced aesthetic value of the waterfalls
AC (accident cost)	Accident costs during construction and O&M are calculated by multiplying the estimated number of deaths and injuries due to the project by the economic value of deaths and injuries.

2.2. Treatment of input uncertainty

This study treats uncertainty in input parameters by running the model probabilistically. Table II shows the main input parameters in the model. The rest of the parameters are found in Table A-I in Appendix. The uncertain input parameters used in this study are represented by the distributions as listed in Table III for the main parameters, and in Table A-I in Appendix for the rest of the parameters. Repeated runs of the model obtain a probability distribution of possible outcomes. Of course, many of the values in Table III and table A-I are tentative and open to criticism, but they represent our best attempts to extract information from the literature and other sources in its present state, and are greatly preferable to ignoring the issue of uncertainty by using single values for inputs that are in reality not well known.

Table II **Main input parameters and descriptions**

Parameter	Units	Description
EO	Rs/MWh	Initial expected increase in economic output due to increased power supply
ε		Proportional reduction in annual number of tourists
P0		Initial proportion of time during which an alternative power generation is unavailable
φ		Annual rate of decrease in proportion of time during which an alternative power generation technology is not available
NT	Persons	Annual number of tourists visiting the dam site in absence of the dam

***Table III*. Main parameter values**[4]

Parameter[5]	Minimum value	Most likely value	Maximum value
EO	10000[a]	26000[b]	118500[c]
ε	0[d]	0.6[e]	0.9[f]
P0	0.1[g]	0.5[h]	0.9[i]
φ	0.04[j]	0.05[k]	0.14[l]
NT	80000[m]	100000[n]	200000[o]

Notes: [a] The estimated losses to the Sri Lankan economy for energy not served in 1990 prices (CEB 1994a); [b] The updated figure for the above cost of energy not served in 1998 prices (CEB 1999); [c] In China, each kWh of power shortage results in a loss of economic output of $0.38-1.5 (MOF 1990); [d] Assuming the loss of waterfalls aesthetics does not affect tourism in the area at all since tourists can visit other attractions in the area; [e] This figure is a rate of decrease in number of tourists after the terrorist attack in Colombo & Kandy during the 1st quarter of 1998. Source: CBSL (2000); [f] Assuming majority of tourists only visit the dam site to see the waterfalls; [g] The 1991 drought in Sri Lanka caused power cuts for about 1.5 months. i.e., P0=1.5/12=0.1 (De Silva 1992); [h] The most recent droughts in Sri Lanka occurred in 1996, which caused power cuts for approximately 6 months. i.e., P0=6/12=0.5 (CEB); [i] Kenya has a similar power generation system to Sri Lanka. Kenya introduced power cuts in September 1999 due to serious droughts and lasted for one year[6]. i.e., 12/12=1. This value could be justified since to build an alternative power generation plant in a year would be difficult. This is because, for example, plans of building thermal power plants in Sri Lanka are often postponed as a result of environmentalist group protests. A more modest figure of 0.9 is used in this study as the value seems slightly too high; [j] The electrification rate in Sri Lanka is likely to be increased by 28% within 7 years (1999-2005). Thus, an annual rate of decrease in EO is assumed to be 28/7=4% (CEB 1999); [k] The CEB intends to increase the electrification rate in Sri Lanka by 38% within 7 years (1999-2005) Thus, an annual rate of decrease in EO is assumed to be 38/7=5% (CEB 1999); [l] Positive impacts of an increased electricity supply due to the UKHP on economic growth decrease, as power shortage problems become less serious. The estimated energy deficits in a driest condition in 1999 and 2000 are 470GWh and 404GWh respectively. Therefore, The power shortage problem is becoming less serious at the rate of 14% per annum (CEB 1999); [m] Assuming 20% less than the most likely value, as number of foreign tourists in Sri Lanka is decreasing due to political instability; [n] Average number of tourists visiting the dam site (CEB 1994a); [o] Assuming the number could double in the absence of the dam, as the project area is one of the most popular places for tourists, both domestic and foreign.

2.3. Results

A simulation with 10000 iterations was run. Figure 1 is a graphical presentation of the mean values for the nine variables described in Table I in each year (these are values for the year in question, not present values which are shown in Figure 2). Figure 1 shows that CC (construction cost) has a large negative impact just for a short period, i.e., during construction. EG (economic growth) is the most significant benefit in the early years of operation, but it declines over time as alternative power supplies become more available. The other prominent variables are PG (power generation) which has continuing positive impact; and LT (loss in tourism) which has a long-term negative impact. The impacts of CP (clean power), OM (O & M cost), RE (resettlement cost), and AC (accident cost) are not as large. IN (inundation cost) is negligible as the inundated area is not large, nor agriculturally valuable.

Figure 2 shows the present value of mean values for these 9 variables at a 5% annual discount rate. Both costs and benefits are discounted away and tend towards zero after the first 40 years or so. The mean value of the NPV at a 5% discount rate at year 70 is 18 billion Rs.

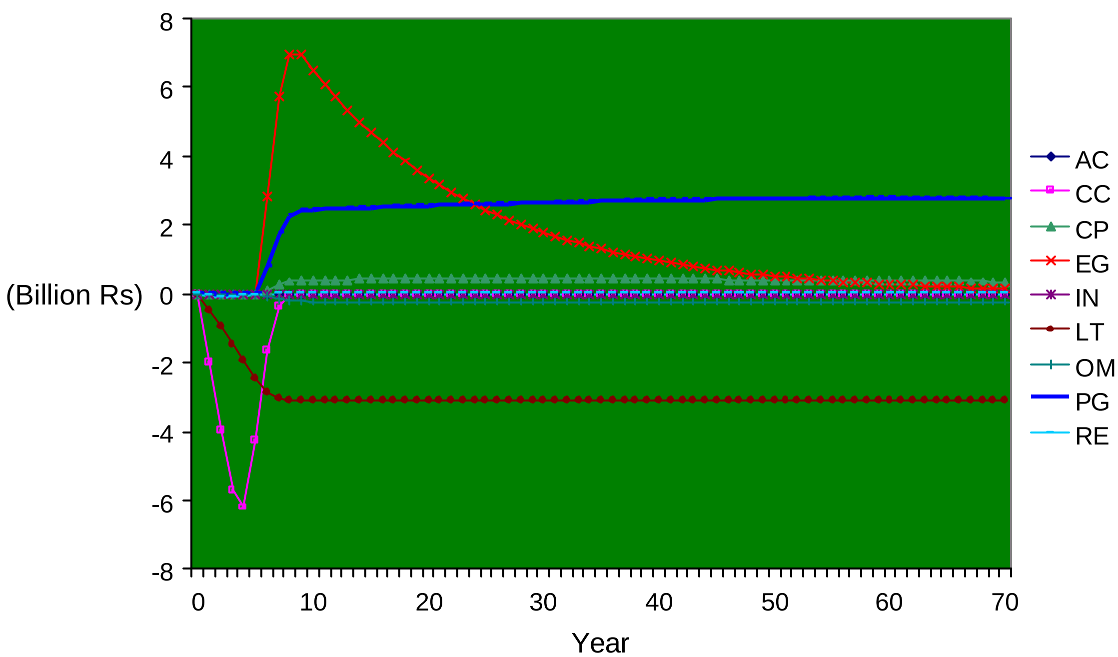
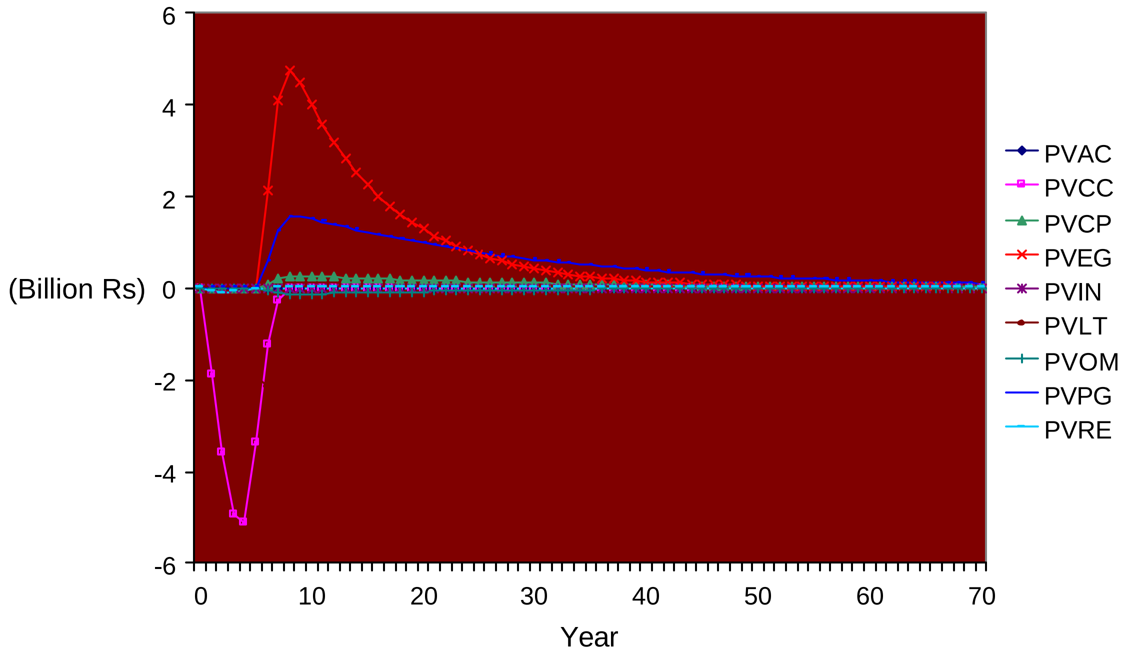


Figure 1. **Mean values for the nine variables of Table 1 by year.**

Figure 2. **Present values of mean values for the nine variables of Table 1 by year.**



2.4. Ranges of the four most influential variables

Figure 1 and 2 show that the variables PG (power generation), EG (economic growth), CC (construction cost), and LT (loss in tourism) have the largest impact on the NPV. After the completion of project construction, the 95th percentile of PG (power generation) starts growing upwards rapidly as shown in Figure 3. Its slope gradually becomes flatter as the rate of changes in electricity prices decrease over time. The mean of PG initially grows slightly upwards because the increase in electricity prices offsets the reduction in electricity generation as a result of sedimentation problems. After year 40, it starts decreasing due to the reverse effect. The 5th percentile of PG initially reflects the impact of construction delay. After construction is completed, it decreases dramatically due to the impact of heavy sedimentation.

The shape of the 95th percentile, the mean and the 5th percentile of EG (economic growth) all has a similar pattern, dropping sharply as shown in Figure 4. This is mainly

Figure 3. **Range of values for PG (power generation) by year.**

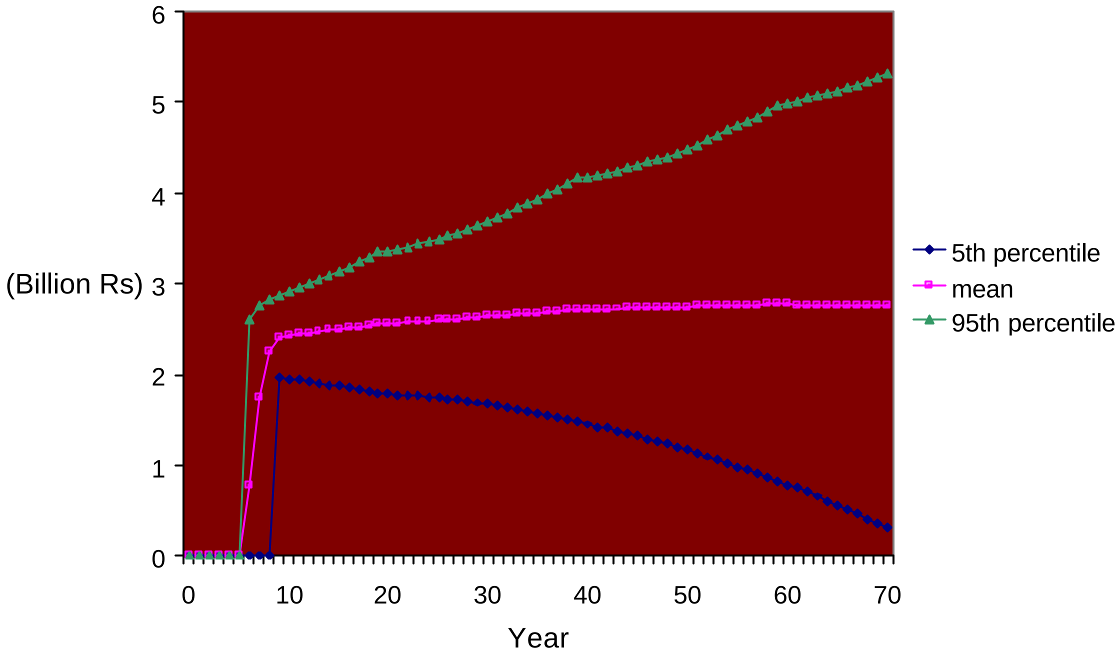
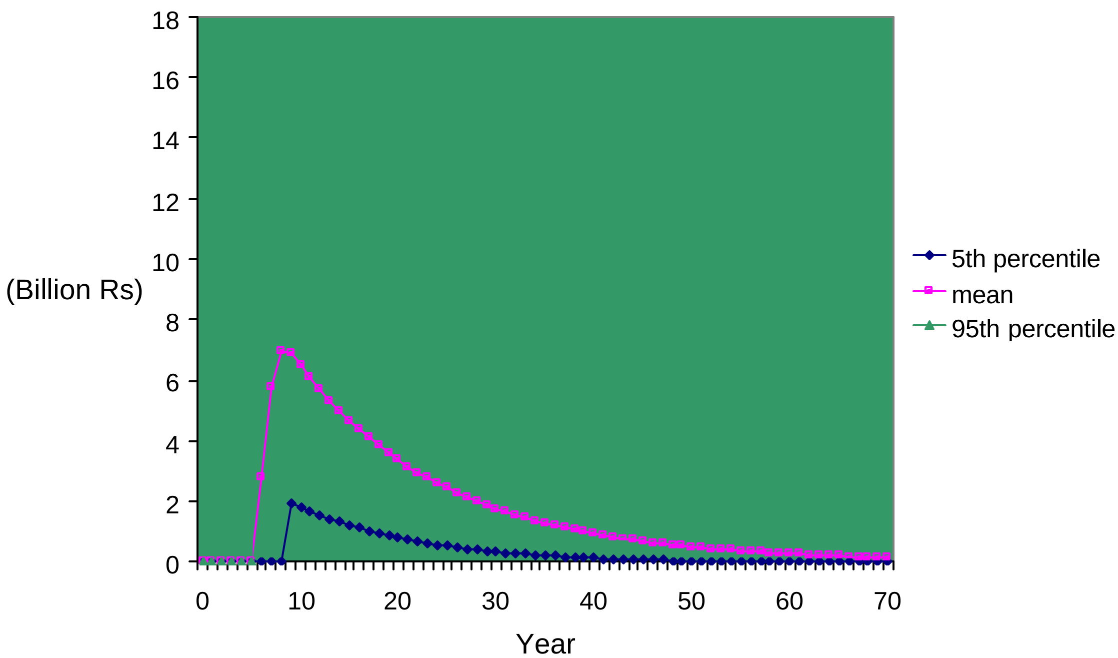


Figure 4. **Range of values for EG (economic growth) by year.**



because of the reduction in the proportion of time during which an alternative power generation technology is unavailable.

Figure 5 shows the 95th percentile, the mean and the 5th percentile of CC (construction cost); as expected they are all initially negative and then become zero after construction finishes.

The 95th percentile, the mean and the 5th percentile of LT (loss in tourism) gradually become negative during the construction period and all become flat after the completion of construction. This is because after the area is completely submerged as a result of the project, loss in tourism revenue due to an aesthetic loss of waterfalls remains stable.

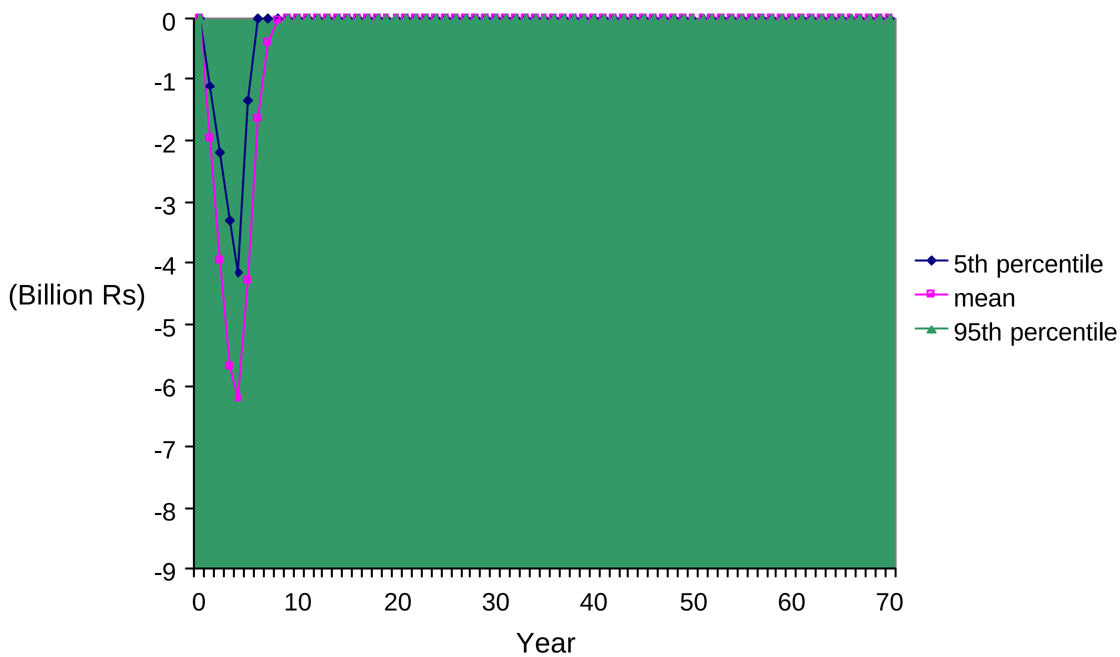
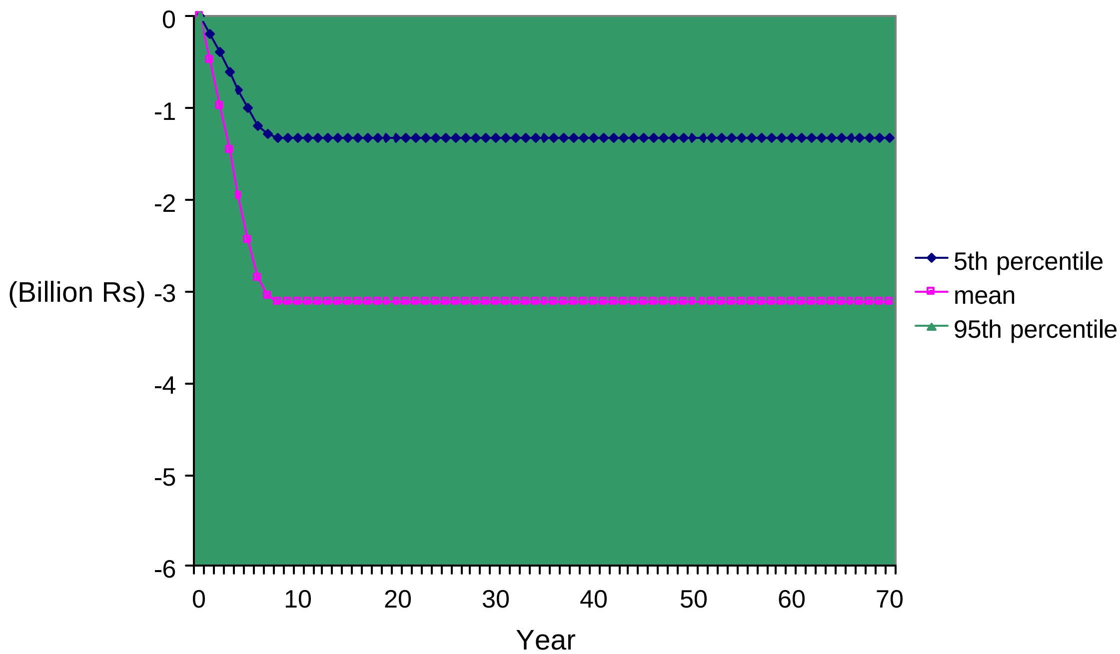


Figure 5. **Range of values for CC (construction cost) by year.**

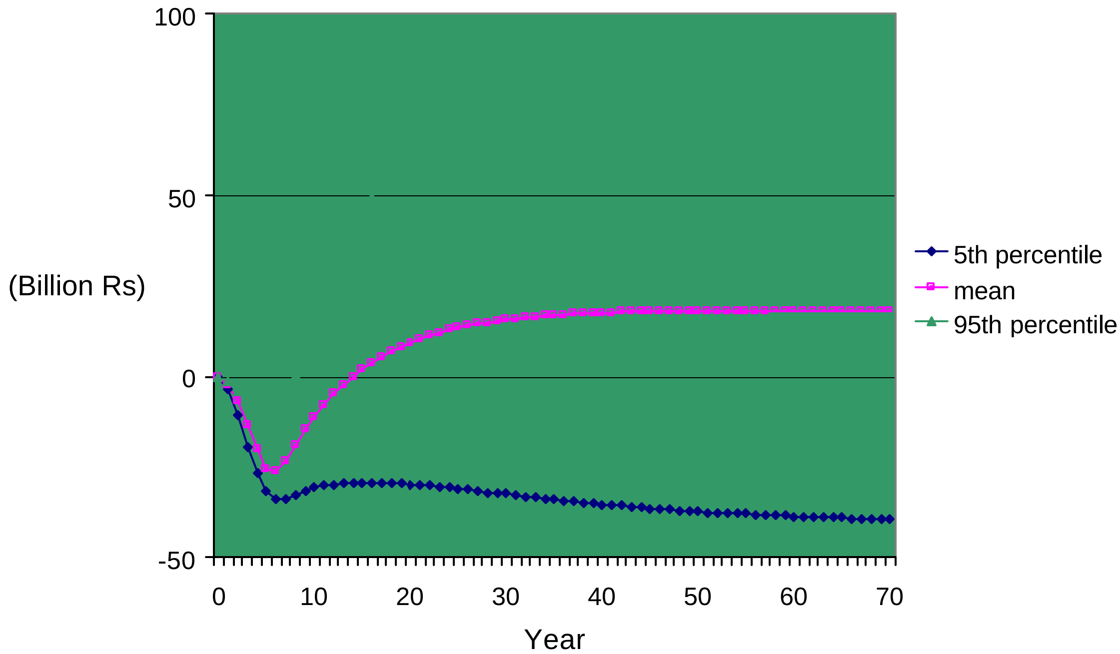
Figure 6. **Range of values for LT (loss in tourism) by year.**



2.4. The NPV at the 5% discount rate

The evolution of the 5th percentile, the mean, and the 95th percentile of the cumulative NPV are shown in Figure 7. The final values are –39, 18, and 91 billion Rs respectively. The cumulative NPV is initially negative, mainly due to the large construction cost. However, the mean and the 95th percentile start growing upwards as the increased power supply makes a contribution towards the country's economic growth; the benefits eventually offset the large initial capital costs. Hence, the 95th percentile and the mean of the cumulative NPV seem to justify the project. The 5th percentile of the cumulative NPV keeps declining gradually, as the reduction in electricity generation and low prices for electricity keep revenues below the on-going costs of operation & maintenance and loss of tourism. Policy makers need to weigh up the 35% risk of having a negative NPV against the expected positive outcome.

Figure 7. **Range of cumulative NPV at the 5% discount rate by year.**



2.5. Sensitivity analysis

Sensitivity analysis using regression identifies the input parameters which are most significant in determining the output, in this case cumulative NPV. Table IV shows that the following parameters from Table II have significant impacts on the cumulative NPV: EO (initial expected increase in economic output due to increased power supply), ε (Proportional reduction in annual number of tourists), P0 (Initial proportion of time during which an alternative power generation is not available), φ (Parameter which describes the annual rate of decrease in proportion of time during which an alternative power generation is not available), NT (Annual number of tourists visiting the dam site in absence of the dam). Hence these parameters should be treated extremely carefully, as the cumulative NPV is sensitive to changes in their values, especially the most significant parameter EO.

Each parameter has a correct sign, consistent with the model. Those parameters that contribute to the benefit have positive signs and those parameters that contribute to the cost have negative signs. Some parameters that might have been expected to have a large impact do not feature in Table IV, for instance construction cost, construction period, change in electricity prices and decline in power generation due to sedimentation.

***Table IV*. Statistically significant parameters.**

Rank	Parameter	Description	Student b coefficient
1	EO	Initial expected increase in economic output due to increased power supply	+ 0.61
2	ε	Proportional reduction in annual number of tourists	- 0.4
3	P0	Initial proportion of time during which an alternative power generation is not available	+ 0.38
4	φ	Parameter which describes the annual rate of decrease in P (proportion of time during which an alternative power generation is not available)	- 0.27
5	NT	Annual number of tourists visiting the dam site in absence of the dam	- 0.27

3. Discounting

One of the criticisms of CBA is the use of discounting (Harley 1992)[7]. Discounting may seem to be incompatible with sustainable development since long-term costs associated with a project are discounted away (Wang.J 1993; Merrett 1997). Harvey (1994) argues that public benefits in the distant future receive very little importance when a policy analysis uses fixed discount rates to value future benefits against present costs. A fixed discount rate is used for temporal consistency and economic efficiency. It is reasonable for short-term effects, though not so for a public policy choice whose effects are long-term and irreversible (Harvey 1994). An alternative to constant discounting is non-discounting. However, non-discounting assigns far too much importance to the distant future (Harley 1992). A disadvantage of non-discounting is that it represents social values that are politically unacceptable. People argue from an economic perspective that using fixed discount rates is the only reasonable method, while others argue from a philosophical perspective that non-discounting is the only reasonable method.

The choice of discount rate is ultimately a political issue. (Harley 1992; Winpenny 1991). The question is what discount rates should be used. There is no single rate that satisfies all the requirements for all projects and the appropriate discount rate is project specific (Lind 1982). It depends on a multitude of factors relating to the structure of the economy, the nature of market-imperfections, the behavior of government, nature of the financing, and the nature of the benefits and the costs.

The same discount rate is usually used throughout the period of analysis in applied CBA studies (Bojo et al. 1992), but this is mostly a matter of convenience. Plambeck et al. (1997) argue that a variable discount rate should be used for long-term analysis because economic and population growth rates vary. One of the main determinants of the discount rate is the rate of economic growth. If the growth rates change in the future, then the discount rate should also change (Plambeck and Hope 1996). According to economic growth theory, the discount rate is expressed by Ramsey's rule,

$$r(t) = y^{*}g(t) + p \tag{1}$$

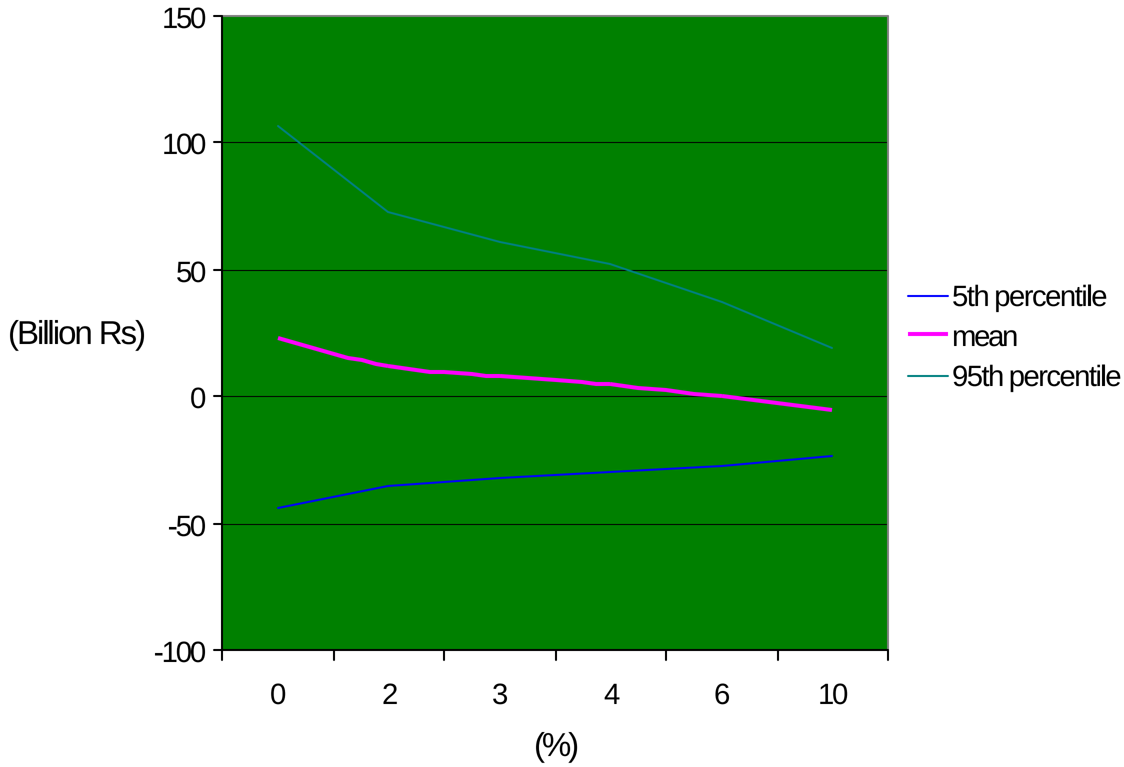
where r(t) = discount rate, y = negative of the elasticity of marginal utility of consumption, p = pure rate of time preference, and g(t) = per capita growth rate of consumption. The value y is usually set to one, corresponding to a logarithmic utility function.

The use of variable discount rate requires a difficult decision on the pure rate of time preference. Azar (1994) and Cline (1992) argue that the use of a positive pure rate of time preference is unethical. This is because it implies that the utility of the current generation is worth more than that of future generation. However, Fankhauser (1994) argues that only a positive rate is consistent with savings and interest rate data. Thus, only positive pure rates of preference are used in this study.

3.1. The cumulative NPV at various discount rates[8]

Figure 8 shows the cumulative NPV computed by the extended CBA model against the pure rate of time preference. The mean values of the cumulative NPV are positive when the pure rate of time preference is low, and become negative when the pure rate of time preference is larger than 6%.

Figure 8. The cumulative NPV against the pure rate of time preference.



4. Conclusions

This paper introduces a new approach to assessing large hydro projects; a CBA model extended to deal with economic, environmental and social issues under uncertainty. In the application to Sri Lanka, although it is likely that a positive cumulative NPV will be obtained, there is also a non-negligible possibility of obtaining a negative cumulative NPV, particularly at higher rates of pure time preference. Therefore, policy makers have to take into account these risks, even though the project might be worth implementing. Hence, each economic, environmental and social factor has to be carefully examined. The variables PG (power generation), EG (economic growth), CC (construction cost), and LT (loss in tourism) appear to have a strong impact on the cumulative NPV. The most significant parameter for the NPV is EO (expected increase in economic output as a result of increased power supply). This extended CBA model seems widely applicable to other cases after some modifications and generalisations, making it a simple and robust tool for this type of project assessment.

The model in this study does not include an option to close down prematurely if the costs start outweighing the benefits. Nor does it contain an expression for decommissioning costs. According to WCD (2000), dam decommissioning costs are presently difficult to predict due to the uncertainty surrounding the various parameters affecting the costs and the limited practical experiences with decommissioning. Decommissioning costs vary from project to project, though they are usually large[9]. This is an area for further development. Finally, the model could be further extended by considering other dam-related issues such as biodiversity, local economic growth, and the broader sociological aspects of resettlement issues.

Acknowledgement

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Notes

1. The issues of destruction of community and psychological distress of resettled people may also arise. These impacts are not included in the model at present.
2. About 70% of the project area is covered by tea land; 23.5% by forest; 4% by homesteads; 1% by paddy; 1% by sparsely used cropland; and 0.5% by grassland (CEB 1994a).
3. One of the concerns about the project is the heavy soil erosion of the area. See Withanage (1998).
4. $1= 79 Rs in November 2000 according to Central Bank of Sri Lanka. This value is used throughout this paper unless otherwise stated.
5. A triangular distribution is used for the variables EO and NT, and a PERT distribution (a special form of beta distribution) is used for the rest of the variables. See Palisade (2000) for more details of the distributions.
6. *'Rainfall is expected to increase slightly between May and August, however, it would not improve water levels in dams until September 2000 when the annual short rains begin'* (www.foxnews.com *May 2000 news* 'Kenya rations power in face of hydroelectric shortfall').
7. See Acocella (1998); Kohli (1993); Walshe and Daffern (1990); Bradford (1997); Broome (1993); Sterner (1994); Price (1993); and Olsthoorn (1999) for discussion of CBA and discount rates.
8. This paper does not discuss an "opportunity cost" approach to discounting, which can be carried out in further study. See e.g., Munasinghe (1995) for discussions of the "opportunity cost" approach.
9. Decommissioning can mean actions such as stopping electricity generation, dam removal and river restoration (WCD 2000). For example, it is approved to spend $225000 to remove the Chair Factory Dam in the US (IRN's *River Revival Bulletin* No 22 November 29 2000). Total removal cost for the Matilija dam in the US would be $22-200 million (IRN's *River Revival Bulletin* No21 October 17 2000).

Appendix

A-I. Model

$PGt = [(QEt*10^3)*PEt]/10^9$		GRs/year,
$PEt = PEo$	for t=0	
$= (1+f)*PE_{t-1}$	for t>0	Rs/MW/year
$QEt = [(t-TS)/(Tc-TS)]*AQE*[1 - a(t - TS)]$	for $TS \leq t \leq Tc$	
$= AQE*(1 - a(t - TS))$	for $t>Tc$	
$= 0$	for $t<TS$	GWh/year
$AQE = LF*GC*(365days*24hours)$		GWh/year
$TS = \delta Tc$		year

where PGt = income from power genation at t in billion Rs, t = year 0….T, QEt = quantity of electricity generated in GWh/year, PEt=price of electricity in Rs/MW/year, PEo = initial price in electricity in Sri Lanka in Rs/MW/year, f = instantaneous proportional annual changes in electricity prices in Sri Lanka, Tc = construction period, TS = time of hydropower station starts operating, AQE = annual quantity of electricity generated in GWh/year, a = annual rate of decline in power generation due to sedimentation, LF = load factor, GC = generating capacity in GW, and δ = parameter which describes the time of hydropower station starts operating.

$CPt = (1 - Pt)*CP't$	GRs/year
$CP't = [(QC*BC + QG*BG)*10^6]/10^9$	GRs/year
$QC = \gamma*QE$	GWh/year
$QG = (1 - \gamma)*QE$	GWh/year
$Pt = P0*exponential(-\varphi t)$,	

where CPt = environmental benefit from generating clean power during the time when an alternative power generation technology is available in billion Rs, CP’t = environmental benefit from generating clean power in billion Rs, Pt=proportion of time during which an alternative power generation technology is unavailable, QC = amount of electricity generated by coal power in the best alternative scenario (coal+gas turbine) in GWh/year, QG = amount of electricity generated by gas turbine in the best alternative scenario in GWh/year, BC = benefit of avoiding air pollution due to coal power in Rs/kWh, BG = benefit of avoiding air pollution due to gas turbine in Rs/kWh, γ = parameter which describes the proportion of electricity generated by coal in the best alternative scenario, P0 = initial proportion of time during which an alternative power generation is unavailable, and φ = annual rate of decrease in Pt.

$$EGt = Pt*EG't \qquad \text{GRs/year}$$

$$EG't = [(QEt*10^3)*EO]/10^9 \qquad \text{GRs/year}$$

where EGt = benefit of economic growth facilitated by increased power supply during the time when an alternative power generation technology is not available in billion Rs, EO = initial expected increase in economic output due to increased power supply in Rs/MWh.

$$CCt = MCC*t/TMCC \qquad \text{for } t \le TMCC$$

$$=[(1 - (t - TMCC))/(Tc - TMCC)]*MCC \qquad \text{for} TMCC < t \le Tc \qquad \text{GRs/year}$$

$$MCC = (2*TCC)/Tc \qquad \text{GRs}$$

$$MTC = \alpha Tc \qquad \text{year}$$

where CCt = construction cost of the UKHP in billion Rs, MCC = max construction costs in billion Rs, TCC = total construction costs in billion Rs, MTC = time when constrcution costs reach their maximum value, and α = parameter which describes the location of the peak of the distribution for CC during the construction period[1].

$$OMt = [(GC*10^6)*OMC]/10^9 \quad \text{for } t>TS \quad \text{GRs/year}$$

where OMt = operation and maintenance cost of the UKHP in billion Rs, GC = electricity generating capacity in GW, OMC = annual O&M cost estimate in Rs/kw/yr

$$REt = MRE*t/TMRE \quad \text{for } t \le TMRE$$

$$= [(1 - (t - TMRE))/(Tc - TMRE)]*MRE \quad \text{for } TMRE<t\le Tc \quad \text{GRs/year}$$

$$MRE = (2*TRE)/Tc \quad \text{GRs}$$

$$TMRE = \beta Tc \quad \text{year}$$

where REt = resettlement cost in billion Rs, MRE = max resettlement costs in billion Rs, TRE = total resettlement costs in billion Rs, TMRE = time when resettlement costs reach their maximum value, and β = parameter which describes the location of the peak of the distribution for RE during the construction period.

$$INt = (EL*t)/Tc \quad \text{for } t\le Tc$$

$$=EL \quad \text{for } t>Tc \quad \text{GRs/year}$$

where INt = economic losses due to inundation of land in billion Rs, EL = economic losses due to inundation of the land in the project area in billion Rs [2].

$$LTt = (TRRt*NT*RS)/10^9 \quad \text{GRs/year}$$

$$TRRt = \varepsilon*t/Tc \quad \text{for } t<Tc$$

$$= \varepsilon \quad \text{for } t\ge Tc$$

[1] This is because the construction cost may not be exactly the same every year.
[2] This is calculated by expressing the lost value of the submerged land in monetary terms. CEB (1987) evaluates monetary values for each land type (e.g., tea land etc).

where LTt = loss in tourism revenue in billion Rs, TRRt = rate of reduction in number of tourists due to the project, NT = annual number of tourists visiting the area of the dam site in absence of the dam in persons, RS = per capita tourists recipients in the dam site in Rs, ε = proportional reduction in annual number of tourists.

$ACt = \sum_{i=1}^{2} ACCit$	i=1,2	GRs/year
$ACC_{1t} = [VD*(DCt + DOMt)]/10^3$		GRs/year
$ACC_{2t} = [VM*(INCt + IOMt)] /10^3$		GRs/year

where ACt = accident cost for the UKHP in billion Rs, ACC_{1t} = estimated annual costs of deaths due to accidents in billion Rs, ACC_{2t} = estimated annual costs of injuries due to accidents in billion Rs, VD = value estimate for deaths in MRs/death, VM = value estimate for injuries in MRs/injury, DCt = annual number of deaths during the construction period, INCt = annual number of injuries during the construction period, DOMt = annual number of deaths during the O&M period, IOMt = annual number of injuries during the O&M period.

$DCt = MDC*t/TMDC$	for $t \le TMDC$	
$=[(1 - (t - TMDC))/(Tc - TMDC)]*MDC$	for $TMDC < t \le Tc$	deaths/year,
$MDC = (2*TDC)/Tc$		deaths
$TDC = GC*DCR$		deaths
$TMDC = \sigma Tc$		year

where MDC = maximum number of deaths during the construction period, TDC = total number of deaths during the construction period, DCR = annual number of deaths during the construction period in deaths/GW/year, TMDC = time when number of deaths reaches maximum during the construction period, and σ = parameter which describes the location of the peak of the distribution for number of workers' deaths/injuries[3].

INCt = MINC*t/TMINC	for t≤TMINC	
=[(1 - (t - TMINC))/(Tc - TMINC)]*MINC	for TMINC<t≤Tc	injuries/year
MINC = (2*TINC)/Tc		injuries
TINC = GC*MCR		injuries
TMINC = σTc		year

where MINC = maximum number of injuries during the construction period, TINC = total number of injuries during the construction period, MCR = annual number of injuries during the construction period in injuries/GW/year, TMINC = time when number of injuries reaches maximum during the construction period.

DOMt = (GC*DCR')/Tc	for t≥TS	
=0	for t<TS	deaths/year
IOMt = (GC*MCR')/Tc	for t≥TS	
=0	for t<TS	injuries/year

where DCR' = annual number of deaths during the O&M period in deaths/GW/year, and MCR' = annual number of injuries during the O&M period in injuries/GW/year

TBt = PGt + CPt + EGt	GRs/year

[3] Number of deaths/injuries may not be the same every year.

$$TC_t = CC_t + OM_t + RE_t + IN_t + LT_t + AC_t \qquad \text{GRs/year}$$

$$NPV_T = \sum_{t=0}^{T} (1+dt)^{-t} (TB_t - TC_t) \qquad \text{GRs/year}$$

where TB = total benefits, TC = total costs, dt = discount rate (fixed/variable), and NPV_T = net present value at time T.

***Table A-I.* Parameter values and descriptions**.

Parameter	Units	Distribution[4] (min, most likely, max)	Descriptions
PEo *(Initial price of electricity)*	Rs/MWh	Pert (4100, 4600, 5500)	The minimum value is 10% less than the most likely value. The most likely value is an average electricity price in 2000 (CBSL 2000). The maximum value is 20% more than the most likely value.
Tc *(Construction period)*	Years	Pert (5, 6, 10)	The minimum value is the original plan (CEB 1994a). According to the WCD Cross-Check Survey, 40% of delayed projects shows a 1-year delay of project schedule (WCD 2000). Similarly, about 5% shows 5 years delay (WCD 2000).
f20 *(expected annual rate of change in electricity prices during 2000-2020)*		Δ (-0.013, 0.018, 0.026)	This estimation is based on the past trend of change in electricity prices in Sri Lanka. The rates of change in electricity prices in 1980, 1987, and 1992 are -0.013, 0.018, and 0.026 respectively (Pesaran et al. 1998). Figure A-I in Appendix shows that the points are clustering around the rate of zero and the above three figures can be assumed to best represent a long-term trend. These minimum and maximum values are also used for f40, f60 and f80.
f40 *(expected annual rate of change in electricity prices during 2020-2040)*		Δ (-0.013, 0.014, 0.026)	The most likely value for f40 is assumed to be 20% less than the most likely value for f20.
f60 *(expected annual rate of change in electricity prices during 2040-2060)*		Δ (-0.013, 0.011, 0.026)	The most likely value for f60 is assumed to be 20% less than the most likely value for f40.
f80 *(expected annual rate of change in electricity prices during 2060-2080)*		Δ (-0.013, 0.009, 0.026)	The most likely value for f80 is assumed to be 20% less than the most likely value for f60.

[4] Δ (.) refers to a triangular distribution and Pert (.) refers to a PERT districution.

a (*parameter which describes the location of the peak of the distribution for the construction cost*)		Pert (0.2, 0.7, 0.8)	The peak is more likely to come near the end of the construction period than the beginning. See Figure A-II in Appendix.
TCC (*total construction cost*)	GRs	Pert (19, 25, 27)	The minimum value is the planned figure (CEB 1994a). 70 hydropower projects commissioned between 1915 and 1986 financed by the World Bank show average cost overruns of about 30% (Bacon and Besant-Jones 1998). Average cost overruns for large dams excluding extreme cases are 40% (WCD 2000).
b (*parameter which describes the location of the peak of the distribution for the resettlement cost*)		Pert (0.2, 0.3, 0.5)	The peak is more likely to come near the beginning of the construction period than the end. See Figure A-III in Appendix.
s (*parameter which describes the location of the peak of the distribution for number of workers' death /injuries*)		Pert (0.1, 0.5, 0.8)	Assuming the peak of the distribution is at the beginning while completing fundamental work for the minimum value. Assuming more complicated and large scale-dangerous work is carried out in the middle of the construction period for the most likely value. Assuming the peak of the distribution is towards the end of the construction period for the maximum value.
g (*parameter which describes the proportion of energy generated by coal in the best alternative scenario (coal + gas turbine)*)		Pert (0.8, 0.98, 1)	For the minimum value, assuming a minimum 80% of power would be generated by coal in the best alternative scenario. This is because coal is currently the dominant fossil fuel power generation technique in Sri Lanka. The most likely value is based on the current best alternative scenario (CEB 1994a). Assuming all the energy is generated by coal in the best alternative scenario for the maximum value.

BC (*benefit of avoiding air pollution due to coal power*)	Rs/KWh	Pert (0.06, 1.37, 1.39)	The minimum value is the damage cost caused by NOx (the lowest among four pollutants, NOx, SO_2, particulates, and CO_2) emitted by coal power in the best alternative scenario (CEB 1994a). The most likely value is the total damage cost caused by air pollution (SO_2, NOx, particulates, and CO_2) emitted by coal power in the best alternative scenario (CEB 1994a). The maximum value is the damage cost Damage caused by air pollution emitted by general thermal power generation (CEB 1994a).
BG (*benefit of avoiding air pollution due to gas turbine*)	Rs/KWh	Pert (0.004, 1.14, 1.39)	The minimum value is the damage cost caused by particulates (the lowest among four pollutants, particulates, SO_2, NOx, and CO_2) emitted by gas turbines in the best alternative scenario (CEB 1994a). The most likely value is the total damage cost caused by air pollution emitted by gas turbines in the best alternative scenario (CEB 1994a). The maximum value is the damage cost caused by air pollution emitted by general thermal power generation (CEB 1994a).
EL (*economic losses due to inundation of land in the project area*)	GRs/year	Pert(0.0017,0.002,0.0021)	The inundation effect is supposed to be low as the project is a run-of-the-river type. Assuming 20% lower than the estimated value since productivity of the affected land is considered to be low for the minimum value (CEB 1994a). Assuming 5% less land is inundated than the estimated value for the most likely value. Tea land will be mainly affected by the project due to the various project structures. The maximum area of affected tea land is estimated at 50ha in total. Annual monetary losses due to inundation are estimated as 42000Rs/ha/year. This rate is used for the maximum value (CEB 1994; CEB 1987).
TRE (*total resettlement cost*)	GRs	Pert (0.33, 0.45, 0.5)	The minimum value is the planned figure (CEB 1994a). The actual number of resettled people is 35% higher than the estimated figure according to the WCD Cross-Check Survey (WCD 2000). The actual number is 47% higher than the estimated figure among the projects financed by the World Bank (World Bank 1996).

RS *(per capita tourists receipts in the Dam site)*	Rs/year	Pert(38000,42000, 63000)	The minimum value is 10% less than the most likely value by assuming that local tourists spend less. The most likely value is the per capita tourist receipts in Sri Lanka. (CBSL 1998). The maximum value is 50% more than the most likely value by assuming that foreign tourists spend more.
GC *(generation capacity)*	GW	Pert (0.1, 0.14, 0.15)	The current planned installed capacity is 0.15 GW (CEB 1994a). The energy output of Victoria Dam in Sri Lanka is about 31% lower than the planned figure (WCD 2000). The WCD Cross-Check Survey shows that over half of the projects in the sample generate less power than the planned figure. The most likely case is 10% below the target (WCD 2000).
OMC *(operation & maintenance cost)*	Rs/kW/year	Pert (1300, 1700, 1800)	The minimum value is the planned figure of 1300 Rs/kW/year (CEB 1994a). The same rates are used as for TCC, that is 30% and 40% more than the planned figure for the most likely and maximum values respectively.
VD *(value estimate for deaths)*	MRs/death	Pert (33, 60, 550)	This minimum value is obtained from the China's Three Gorges Dam Project. A wife of a worker who was killed by a construction accident claimed $418,116 for compensation (China News Service 13 October 2000). The most likely value is the estimated value of a statistical life obtained from regression analysis using the data from India (Shanmugam 2000). The maximum value is the maximum value of the range of the recent estimate of a statistical life in developed countries (Viscusi 1993).

VM *(value estimate for injuries)*	MRs/injury	Pert (0.009, 0.03, 3.3)	The minimum value is the minimum value of the estimated range of the statistical injury values obtained from regression analysis using the data from India (Shanmugam 2000). The most likely value is the maximum value of the estimated range of the statistical injury values obtained from regression analysis using the data from India (Shanmugam 2000). The maximum value is the average estimated value of injury from developed countries in the past studies (Shanmugan 2000).
DCR *(estimated annual number of deaths during the construction period)*[5]	Deaths/GW/yr[6]	Δ (0.3, 0.8, 1.9)	The minimum value is the estimated value for the Hoover Dam in US (Inhaber 1982; Easton Express 1979). The most likely value is the estimated value in the Canadian Ontario case (Inhaber 1982; Morison 1977). The maximum value is the estimated value in the French hydropower case (Inhaber 1982; Potier 1969).
MCR *(estimated annual number of injuries during the construction period)*	Injuries/GW/yr	Δ (170, 310, 340)	The minimum value is assumed to be a half of the Inhaber's estimate below since technology has improved compared to the time when these figures were estimated. Technology improvements such as better equipment or facilities are likely to reduce the number of accidents. The most likely value is 10% less than the Inhaber's estimate below. The maximum value is the estimated value for the past projects (Inhaber 1982; Potier 1969).
DCR' *(estimated annual number of deaths during the O&M period)*	Deaths/GW /yr	Δ (0.32, 0.57, 0.63)	The minimum value is assumed to be a half of the Inhaber's estimate below since technology has improved. The most likely value is 10% less than the Inhaber's estimate below. The maximum value is the estimated value for the past projects (Inhaber 1982; Potier 1969).

[5] The construction workforce is estimated to be 1000 persons on average, and 2000 persons during the peak period (CEB, 1994a).

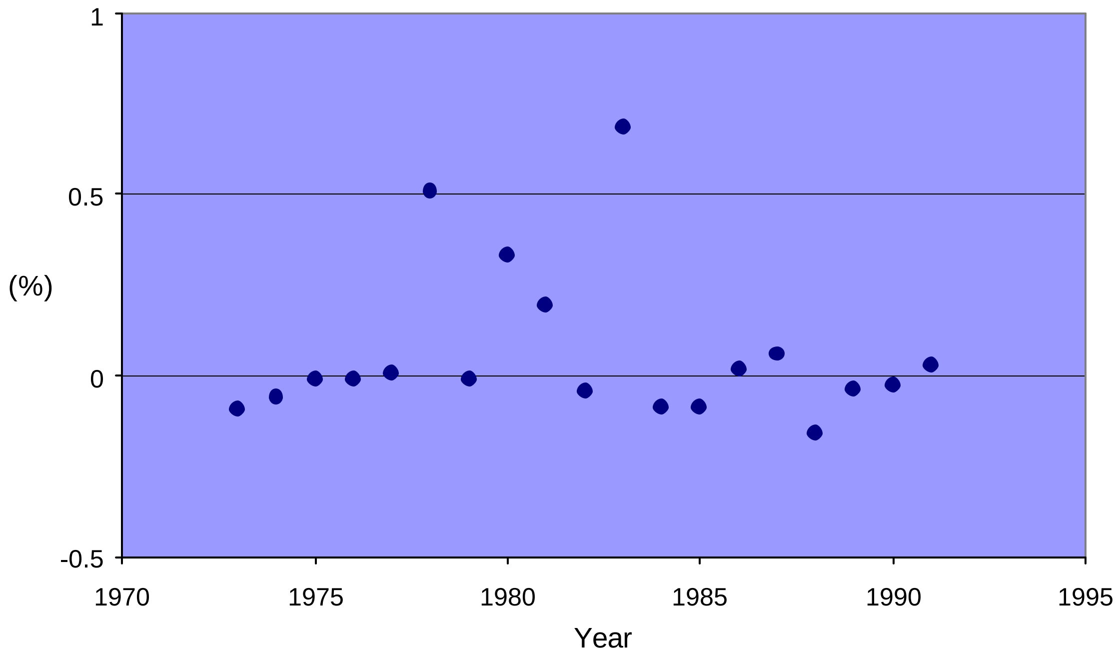
[6] Number of accidents (deaths/injuries) is likely to increase as construction period becomes longer.

MCR' *(estimated annual number of injuries during the O&M period)*	Injuries/GW/yr	Δ (7, 12, 13)	The minimum value is assumed to be a half of the Inhaber's estimate below since technology has improved. The most likely value is 10% less than the Inhaber's estimate below. The maximum value is t he estimated value for the past projects (Inhaber 1982; Bertoletta and Fox 1974).
a *(annual rate of decline in power generation due to sedimentation)*[7]		Pert (0, 0.001, 0.03)	Assuming no sedimentation problem for the minimum value, since it is not a significant issue in the UKHP case according to CEB (1994a). However, this issue involves huge uncertainty. The samples examining the rate of loss of active storage due to sedimentation in the WCD Cross-Check Survey are clustering around a line of 0.1% annual loss (WCD 2000)[8]. The maximum value is the maximum annual rate of loss of active storage due to sedimentation in the WCD Cross-Check Survey. A relatively high rate is set in order to challenge project optimism (WCD 2000).

[7] Experiences of dams worldwide in the past show that sedimentation problems are common issues. See for example, WCD (2000); Smith (1999); Dixon (2000); Leopold (1998); Chunhong (1995).

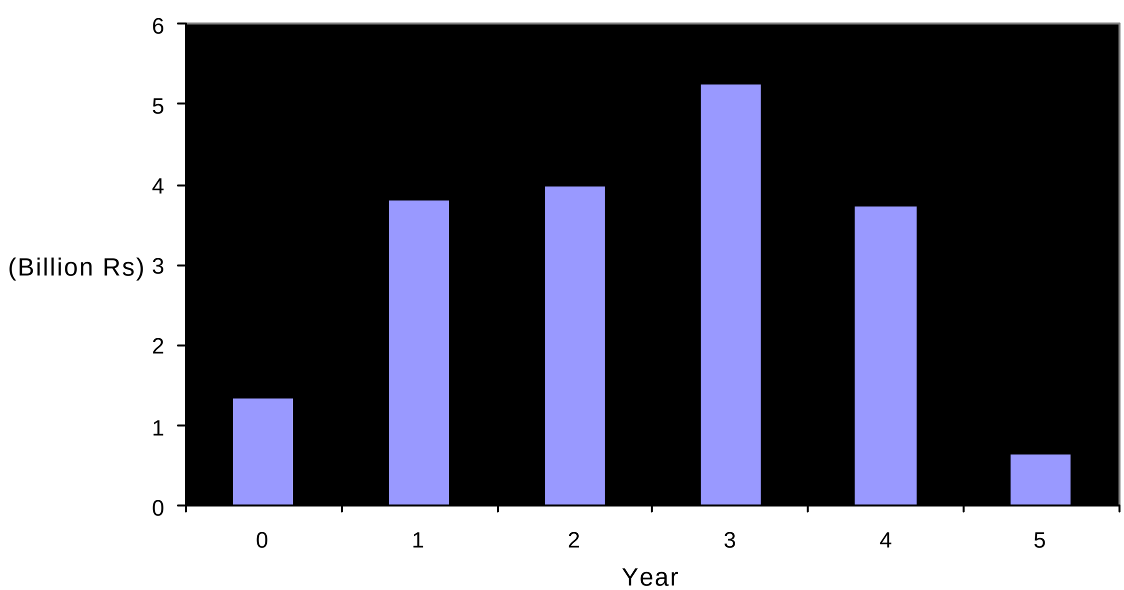
[8] A sample of 47 dams is chosen, and age of dams against % active storage loss is plotted. See Figure 2.14 in WCD (2000) p.65. Assuming storage volumes and power generations have a positive linear relationship.

Figure A-1. **Rate of changes in electricity prices in Sri Lanka.**[9]



Source: Pesaran et al. (1998)

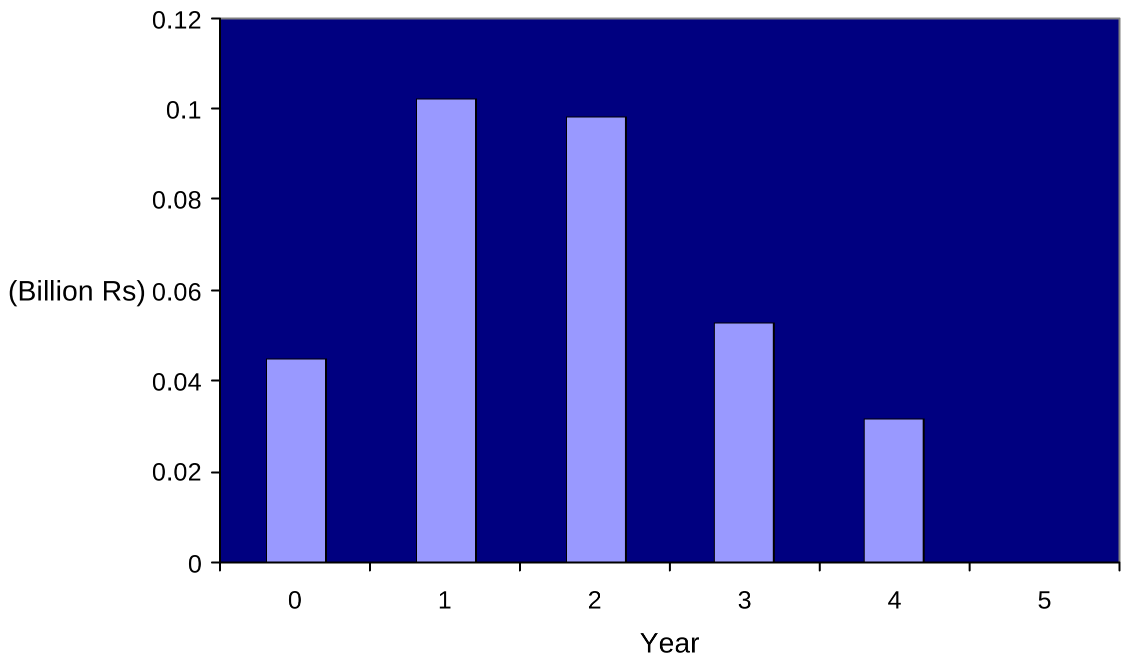
Figure A-II. **Distribution of the construction cost**



Source: CEB (1994a)

[9] The rate of changes in Sri lanka Electricity Constant 1992 prices (Rs/TOE) between 1973-1992.

Figure A-III. **Distribution of the total resettlement cost**



Source: CEB (1994a)

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